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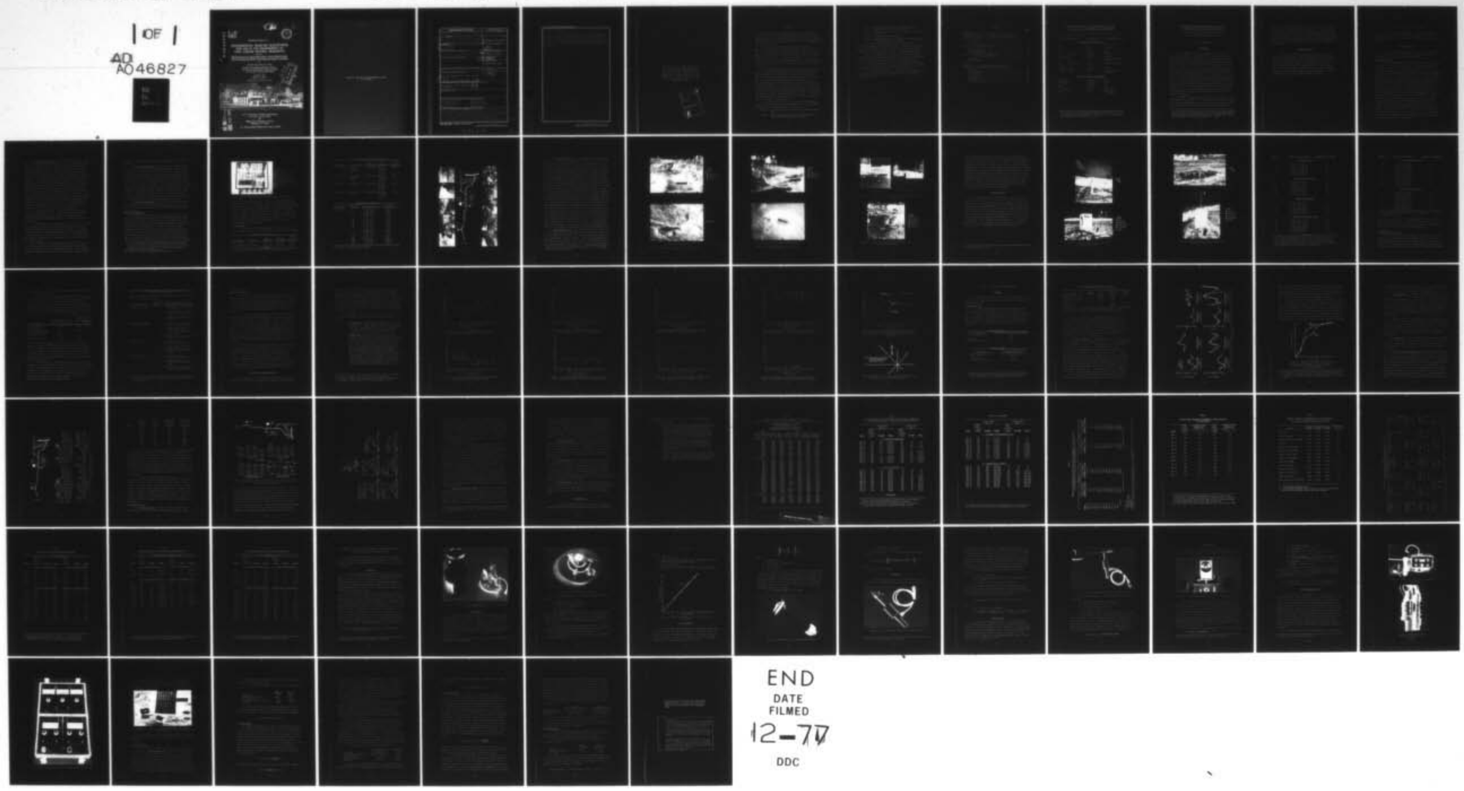

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TECHNICAL REPORT M-77-4

# ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

Report 2

## WATER-QUALITY, METEOROLOGIC, AND HYDROLOGIC DATA COLLECTED WITH AUTOMATED FIELD STATIONS

by

Harold W. West, Herman M. Floyd

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U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180



September 1977
Report 2 of a Series

Approved For Public Release; Distribution Unlimited



Prepared for Directorate of Facilities and Engineering
Fort Carson, Colorado 80913
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The study reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) from 1 August 1975 to 20 April 1977 to aid the Directorate of Facilities and Engineering (DFAE) at Fort Carson, Colorado, in initiating a long-range program to improve the management of the installation's natural resources and the maintenance of environmental quality.

The WES developed the reliable instrumented environmental data system that was used to acquire the quantitative data reported. (Continued).

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20. ABSTRACT (Continued).

This report describes the rationale used to select the water-quality, meteorologic, and hydrologic parameters that were measured and recorded, and the system of instruments used to collect the data. Examples of the data collected are also presented. Preliminary analyses were made of some of the data collected on water-quality, meteorologic, and hydrologic conditions, and comparisons were made with the state of Colorado water-quality standards and surrounding meteorological conditions as observed at nearby weather stations.

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## PREFACE

The study reported herein was conducted from 1 August 1975 to 20 April 1977 at the U. S. Army Engineer Waterways Experiment Station (WES) by personnel of the Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), and of the Instrumentation Services Division (ISD).

The work was authorized by LTC E. R. Hall, Directorate of Facilities and Engineering (DFAE), Fort Carson, Colorado, and supports the Fort Carson Long-Range Environmental Program. The overall Program Managers at Fort Carson were Messrs. D. W. Davis (now retired), Land Management Branch, and M. E. Halla, Environmental Office. SGT D. L. Carpenter and SP4 R. L. Wilson, Environmental Office, weekly maintained the water-quality sensors used by the two WES field stations located at Clover Ditch.

The instrumentation and methods used to acquire on-site environmental baseline data on water quality and meteorology were developed under a Department of the Army Project 4A162121A896 "Environmental Quality for Construction and Operation of Military Facilities;" Task 01, "Environmental Quality Management for Military Facilities;" Work Unit 006, "Methodology for Characterization of Military Installations Environmental Baseline," sponsored by the Directorate of Military Construction, Office, Chief of Engineers (OCE), U. S. Army. Partial cost of the Fort Carson work that pertained to environmental monitoring with automated field stations was assumed under the auspices of the OCE program mentioned above as research necessary to field-test and further refine the equipment and procedures.

This is one of six reports of a series entitled "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural Resources." The individual reports are as follows:

Report 1. Development and Use of Wildlife and Wildlife Habitat Data

Report 2. Water-Quality, Meteorologic, and Hydrologic Data Collected with Automated Field Stations

Report 3. Inventory and Assessment of Current Methods for Rangeland Conservation and Restoration

Report 4. Analysis and Assessment of Soil Erosion in Selected Watersheds

Report 5. General Geology and Seismicity

Report 6. Description and Use of a Computer Information System for Environmental Baseline Data

The work was conducted under the direct supervision of Messrs. H. W. West, Project Engineer, and J. K. Stoll, Chief, Environmental Simulation Branch (ESB), ESD, and under the general supervision of Messrs. B. O. Benn, Chief, ESD, and W. G. Shockley, Chief, MESL.

Messrs. H. M. Floyd and D. E. Tingle, ISD, were responsible for the installation and monthly maintenance of the automated field stations used to collect water-quality, meteorologic, and hydrologic data. Ms. M. H. Smith, ESB, was responsible for processing the water-quality, meteorologic, and hydrologic data collected with automated field stations. This report was prepared by Messrs. H. W. West and H. M. Floyd.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors of the WES during the study and report preparation. Mr. F. R. Brown was Technical Director.

CONTENTS

## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

| Multiply | By | To Obtain |
|---|---|---|
| **U. S. Customary to Metric (SI)** | | |
| inches | 25.4 | millimetres |
| inches | 2.54 | centimetres |
| feet | 0.3048 | metres |
| miles (U. S. statute) | 1.609344 | kilometres |
| pounds (mass) | 0.4535924 | kilograms |
| parts per million | 1.0 | milligrams per cubic metre |
| miles (U. S. statute) per hour | 1.609344 | kilometres per hour |
| degrees (angular) | 0.01745329 | radians |
| Fahrenheit degrees | 0.555 | Celsius degrees or Kelvins* |
| **Metric (SI) to U. S. Customary** | | |
| micrometres | $3.937007 \times 10^{-5}$ | inches |
| centimetres | 0.3937007 | inches |
| metres | 3.280839 | feet |
| kilograms | 2.204622 | pounds (mass) |
| grams per litre | 8.345 | pounds per 1000 gallons |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = 0.555 (F-32). To obtain Kelvin (K) readings, use: K = 0.555 (F + 459.67).

ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

WATER-QUALITY, METEOROLOGIC, AND HYDROLOGIC DATA COLLECTED WITH AUTOMATED FIELD STATIONS

# PART I: INTRODUCTION

## Background

1. The Department of the Army regulation AR 200-1 requires Directorates of Facilities Engineering (DFAE) to act responsibly in managing installations' natural resources by complying with Federal, state, interstate, and local standards for ambient water quality and water emissions. In accordance with Subpart C of the regulation, the DFAE must identify sources of water pollution and submit reports on pollutant emissions. Installations that do not meet current standards must furnish an Environmental Pollution Control Report (RCS DD-I & L (SA) 1088) proposing remedial measures for the pollution problem. The DFAE at Fort Carson, Colorado, in developing a long-range environmental management program, requested that the U. S. Army Engineer Waterways Experiment Station (WES) acquire water-quality, meteorologic, and hydrologic data to assist in determining the characteristics of the surface waters that exist on or pass through the installation and to provide quantitative data to support the installation's natural resource management programs.

2. The WES has developed and field-tested a reliable instrumented environmental data system* to: (a) sense and record on magnetic cassette tape selected environmental data on site, in real time, and at sampling rates selected by the user; (b) sort and store the recorded data for

* For a detailed description, see H. W. West and H. M. Floyd, "An Automated System for Collecting, Processing, and Displaying Environmental Baseline Data," Technical Report M-76-11, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 39180.

computer processing and retrieval; and (c) display the recorded data in tabular or graphic formats specified by the user. To a large extent, the system operates automatically and substantially reduces the costs and errors incurred in manual data recording and handling. This system, augmented by occasional manual samplings, was used to measure and record data on water quality, meteorology, and hydrology for the program described herein.

## Purpose and Scope

3. This report describes the rationale used in selecting the water-quality, meteorologic, and hydrologic parameters that were measured and recorded and the system of instruments used for data collection. Also included are examples of the detailed data that were collected and sent to DFAE, Fort Carson, Colorado, at approximately five- to seven-week intervals during the study, i.e. from 20 November 1975 through 20 April 1977. Example data are presented on selected parameters and analyses made during the data compilation.

## PART II: DATA COLLECTION PROGRAM

4. The data collection program at Fort Carson was conducted in three major phases: program definition, program execution, and data reduction and presentation. These phases are discussed in the following paragraphs.

### Program Definition

5. The program definition phase of the work involved the selection of (a) parameters to be measured, (b) methods and frequency of measurements, and (c) selection of data collection sites.

#### Parameter selection

6. As stated in paragraph 1, the data obtained were to determine the quality of the surface waters and to provide meteorological data important to natural resource management. Because the data were to support these rather broad objectives, it was important to select parameters that could provide information relevant to a variety of specific management goals. For example, water-quality data were needed to determine if effluent from specific pollution sources, e.g. the vehicle wash racks and the sewage treatment plant, caused extensive water-quality deterioration. Further, it was desired that only a small number of parameters be measured; therefore, these parameters had to be good indicators of general water-quality conditions. Another requirement was that the parameters be measured and recorded continuously to capture the dynamics of the water quality at various times of day, seasons, etc. The primary goals of natural resources management include curtailing wind and water erosion, reestablishing vegetation in areas that are undergoing heavy military use, and enhancing wildlife habitats. To achieve these goals, current management practices at Fort Carson rely heavily on improving the vegetation cover and density. Therefore, the meteorological parameters selected for study were those of importance to reestablishing vegetation, enhancing wildlife habitats, and analyzing surface runoff and soil erosion rates.

7. <u>Water-quality parameters.</u> The water-quality parameters selected for study were dissolved oxygen (D.O.), water temperature, hydrogen ion concentration (pH), and conductivity. Surface water normally contains considerable amounts of oxygen in solution, the amount being strongly dependent on the water temperature and the oxygen demand of polluting material. Natural streams, however, can reaerate or replenish oxygen as the oxygen-deficient water surface comes in contact with the atmosphere. The reaeration rate increases directly as a function of the amount of oxygen deficiency and stream turbulence. If the stream has submersed plants, photosynthesis may increase oxygen content significantly during the daytime, but respiratory activities of plants and animals and oxidation of organic matter often offset this contribution. Also, oxidation from inorganic material will tend to deplete the D.O. in the stream. Under stable conditions, the oxidation process will exhibit a diurnal cycle reflecting temperature fluctuations and photosynthesis-respiration relations. Thus, monitoring of D.O. in surface waters provides a good indicator of stream conditions, and radical changes signal the need for further monitoring and investigation.

8. In general, solubility of oxygen varies with temperature; therefore, interpretation of D.O. values must always be made with the corresponding temperature values in mind. Also, temperature has a significant impact on metabolism, diffusion, and chemical and biochemical reactions.

9. Monitoring of pH has wide applicability for the study of water and wastewater. Extremes in pH can result in fish kills and other significant changes in the flora and fauna in streams. Also, extreme pH levels can cause modification in nutrient solubility and formation of precipitates, etc. A pH range from 6.5 to 8.0 is considered normal for biological life, and values ranging from 6 to 9 are acceptable for many aquatic animals.

10. The electrolytic conductivity of a solution is a measure of its ability to carry a current and is therefore directly proportional to the concentration of all ions from whatever source in the solution. Monitoring conductivity provides a way to detect gross changes in water

conditions such as might occur because of a major spill of a soluble chemical.

11. Meteorologic parameters. The meteorologic parameters that were selected for data collection included rainfall, wind speed and direction, air temperature, and solar radiation. The rainfall pattern on the Fort Carson Reservation is not well known, and attempts to extrapolate rainfall from existing gages have been unsatisfactory. Additional knowledge of local rainfall conditions is needed both to select the vegetation species and irrigation sites that enhance wildlife feeding areas and to improve the design of sediment basins, dams, etc. Wind speed and direction patterns were selected to provide data for locating windbreaks, extrapolating rainfall patterns, and estimating the amount of material removed by wind erosion. The air temperature and solar radiation data will aid in selecting vegetation species that correspond to the temperature and solar radiation patterns at Fort Carson.

12. Hydrologic parameters. Water levels in two sediment basins were measured to provide a basis for analyzing the relations of precipitation, surface runoff, and sediment yield for two small watersheds.*

### Methods and frequency of measurements

13. Two methods were used to collect data on the selected parameters. The primary method made use of an automated field station consisting of one 32-channel Lockheed Electronics Company** (LEC) 101-R digital recorder (Figure 1) interfaced with appropriate transducers that converted the sensed phenomena to a recordable electrical signal. Appendix A provides a description of all the transducers used with the LEC field stations during the study. A second method was to use the same transducers as those used with the automated field station but to make the measurements manually, i.e., the outputs of the water-quality

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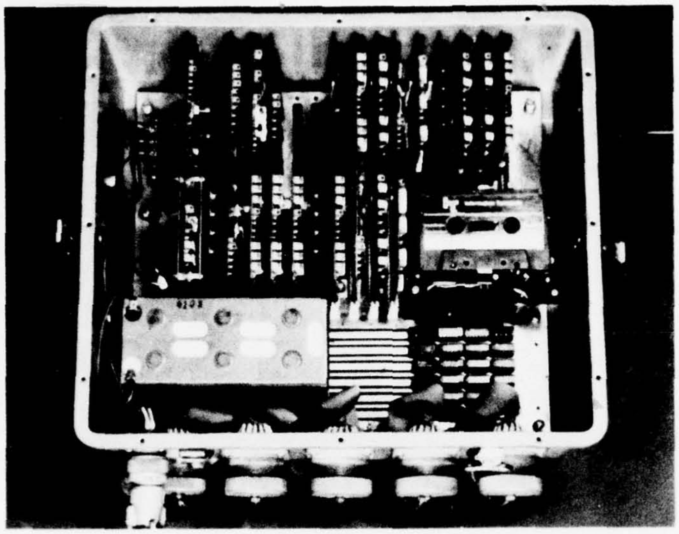
* M. P. Keown and H. W. West, "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural Resources," Technical Report M-77- , Report 4, "Analysis and Assessment of Soil Erosion in Selected Watersheds," July 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** Lockheed Electronics Company, Azusa, California.



SPECIFICATIONS

- Number of data channels (or sensors) – 30
- Sampling rate – 8 channels/sec
- Sampling intervals – 3, 5, 10, 15, 20, 30, 40, 60, 120, and 240 min
- Power source – 4.5 amp-hr (+12 V) rechargeable battery and solar panel
- Data storage – 1/4-in. cassette tape cartridge
- Weight – 10.9 kg (24 lb)
- Size – 20 × 40 × 46 cm

Figure 1. LEC model 101-R field station and specifications

transducers were read with a portable display meter, and the data were recorded manually on a data sheet. Most of the automated field stations were set to record data at 60-min intervals; however, some data were measured and recorded using a 30-min interval (see tabulation in paragraph 17). Manual readings were taken once between 1000 and 1400 hr on 25 March 1976 at 10 sites along Clover Ditch (Figure 2). Manual readings were taken also at two of the same sites (sites 6 and 10) at four different times (20 November and 11 December 1975, 16 January and 8 February 1976) during the study.

Site selection

14. The locations of the water-quality and meteorological sites, along with the dates the data collection was initiated, are listed below.

Automated Field Station Sites

| Site Type | Location | Date Installed | Date Disassembled | Military Grid Coordinates* |
|---|---|---|---|---|
| Meteorological | Red Devil | 20 Nov 1975 | 11 May 1976 | 074636 |
| Meteorological | Turkey Creek | 20 Nov 1975 | 11 May 1976 | 146536 |

(continued)

* Map series V7710; scale 1:50,000 (Fort Carson and vicinity).

Automated Field Station Sites (Concluded)

| Site Type | Location | Date Installed | Date Disassembled | Military Grid Coordinates |
|---|---|---|---|---|
| Meteorological | Red Devil Sediment Basin | 12 May 1976 | Active at the date of this report | 088683 |
| Meteorological | Turkey Creek Sediment Basin | 12 May 1976 | Active at the date of this report | 187544 |
| Water-Quality | Clover Ditch No. 10 | 20 Nov 1975 | Active at the date of this report | 222858 |
| Water-Quality | Clover Ditch No. 6 | 12 May 1976 | Active at the date of this report | 225858 |

Manually Recorded Sites

| Site Type | Clover Ditch Site No. | Data Collection Date | Military Grid Coordinates |
|---|---|---|---|
| Water Quality | 1 | 25 Mar 1976 | 145860 |
| | 2 | 25 Mar 1976 | 155861 |
| | 3 | 25 Mar 1976 | 165860 |
| | 4 | 25 Mar 1976 | 185859 |
| | 5 | 25 Mar 1976 | 220858 |
| | 6* | 20 Nov 1975 | 215858 |
| | 6* | 11 Dec 1975 | 215858 |
| | 6* | 16 Jan 1976 | 215858 |
| | 6* | 8 Feb 1976 | 215858 |
| | 6* | 25 Mar 1976 | 215858 |
| | 7 | 25 Mar 1976 | 235858 |
| | 8 | 25 Mar 1976 | 360853 |
| | 9 | 25 Mar 1976 | 340855 |
| | 10* | 20 Nov 1975 | 245859 |
| | 10* | 11 Dec 1975 | 245859 |
| | 10* | 16 Jan 1976 | 245859 |
| | 10* | 8 Feb 1976 | 245859 |
| | 10* | 25 Mar 1976 | 245859 |

* Location of automated field stations.

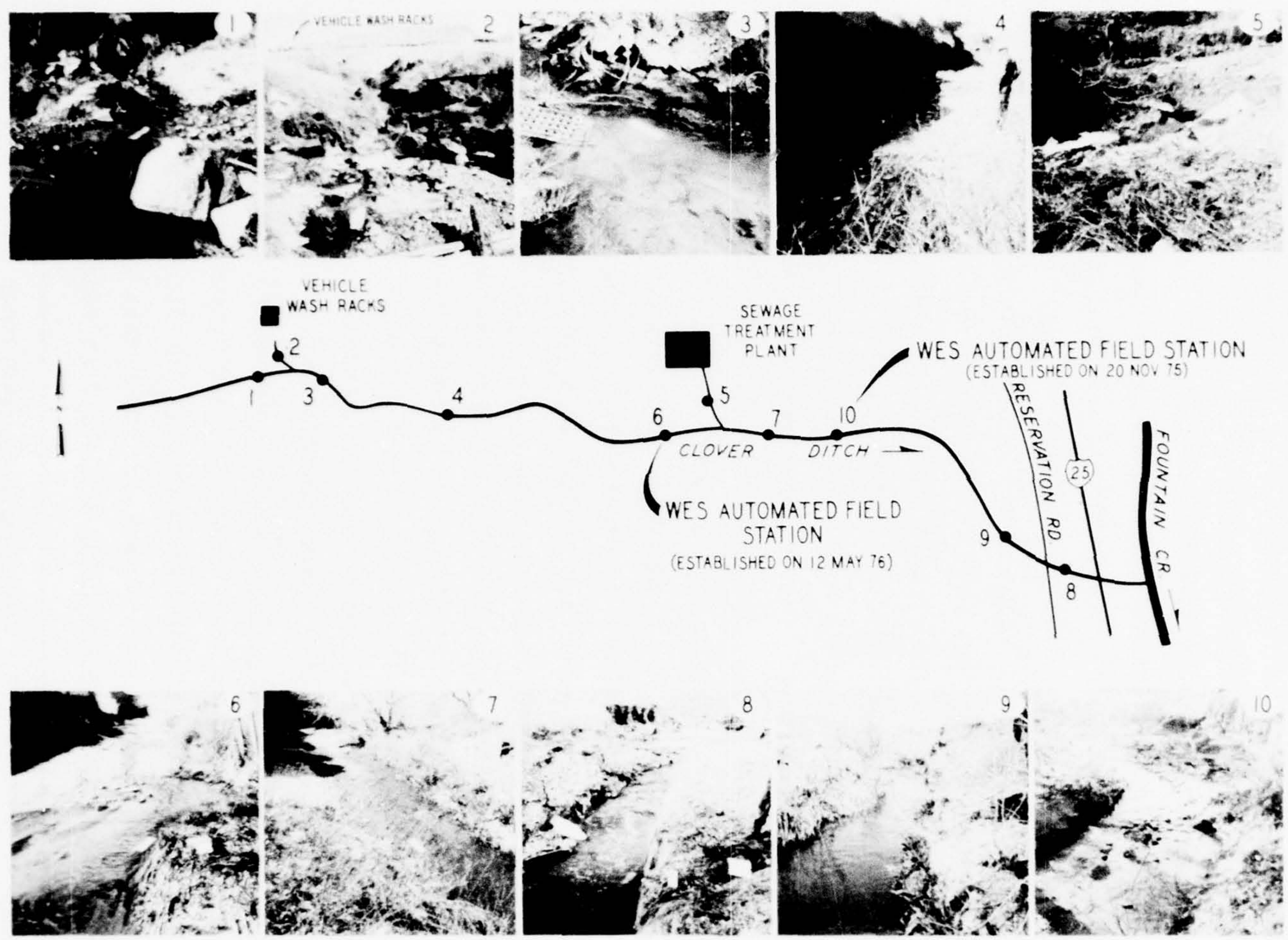



Figure 2. Ten water-quality sites on Clover Ditch

15. Water-quality sites. Both the automated and the manual measurement sites were located along Clover Ditch, passing from the northwest to southeast along the south end of the main cantonment area at Fort Carson. Clover Ditch crosses the eastern boundary of Fort Carson and empties into Fountain Creek, which flows in a southerly direction along Fort Carson's eastern edge. Less than 2 miles* from the eastern boundary, the installation has two sources of effluent that flow into Clover Ditch draining off the reservation into Fountain Creek. These two sources are the sewage treatment plant and the military vehicle wash racks, located at grid coordinates 222859 and 229860, respectively. Two automatic recording stations were located below the outfalls of the sewage treatment plant and the vehicle wash racks (Figure 2) to provide data on the relative degradation of water quality in Clover Ditch caused by each potential pollution source. Figures 3 and 4 show the individual locations of the two automated stations. Because normal water flow in Clover Ditch is low, the locations selected for the automated field stations were in deeper water areas to ensure that the water-quality probes were always submerged. The eight manual-collection sites (Figure 2) were selected to provide data on water quality throughout Clover Ditch from a point above the wash rack outfall to a point just before Clover Ditch empties into Fountain Creek. These data illustrate the fluctuations in water quality along Clover Ditch that can occur with respect to the locations of the outfalls and the automatic data recording stations. Additional data of this type are required to develop trends between flow discharge, automated station recordings, and water-quality profiles for the appropriate reaches of Clover Ditch and Fountain Creek.

16. Meteorological sites. The meteorological data recording stations were located at Red Devil (Figure 5) and Turkey Creek (Figure 6) to provide data on the meteorological conditions along the western and southern boundaries of the reservation. These data will augment those meteorological data presently being collected at Canon City, Penrose,

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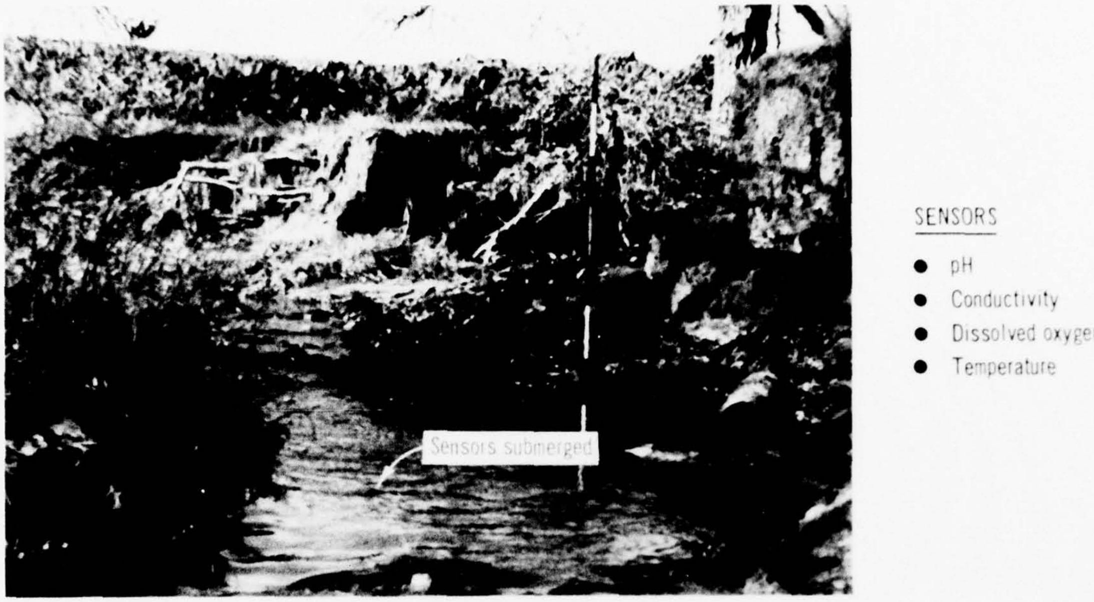
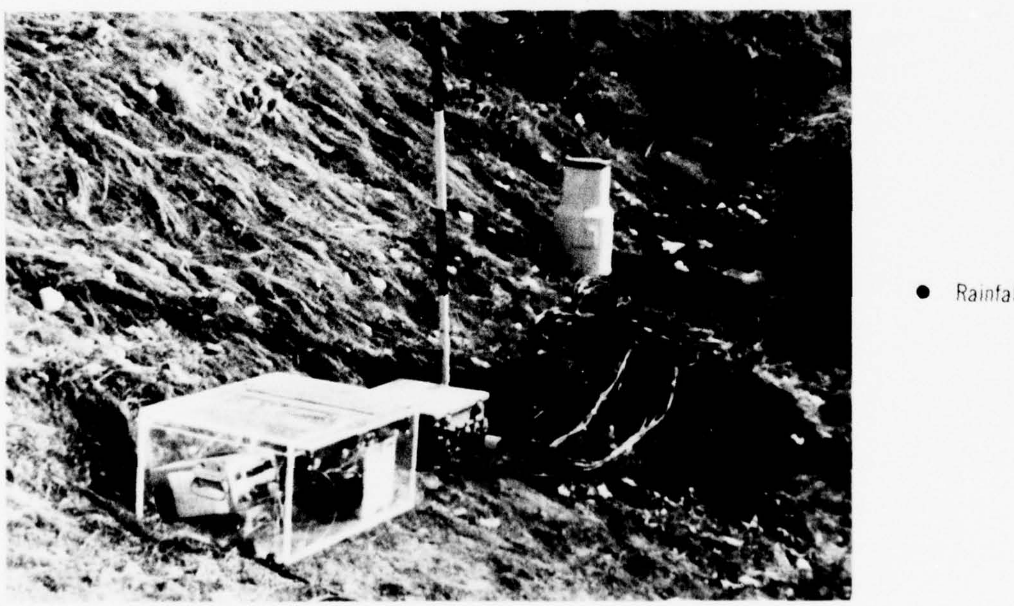
* A table of factors for converting U. S. customary units of measurement to metric (SI) units and metric (SI) units to U. S. customary units is presented on page 5.



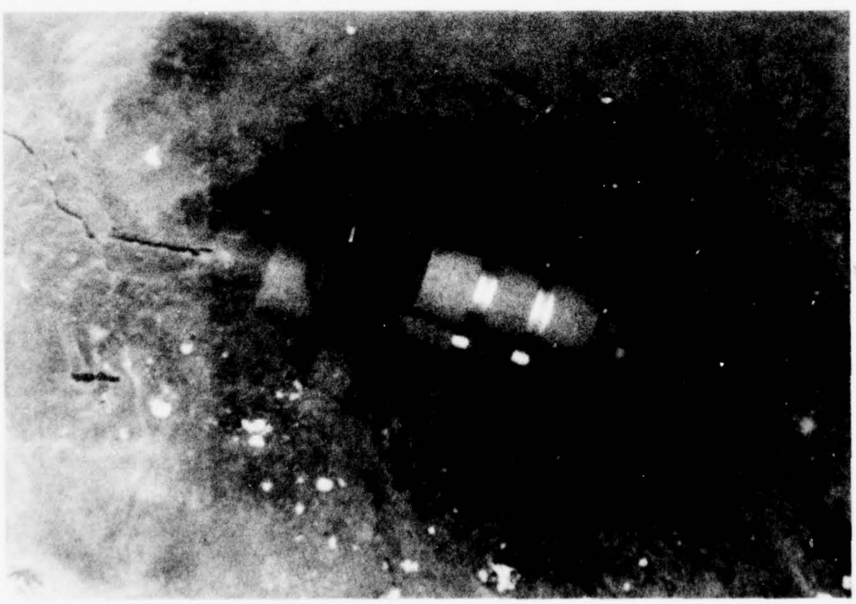

a. Site vicinity




b. Automated field station

Figure 3. Automated field station on Clover Ditch site 10 (Figure 2)


a. Site vicinity



b. Submerged water-quality sensor package

Figure 4. Automated field station on Clover Ditch site 6 (Figure 2)


a. Sensors

b. Field station on roof

Figure 5. Red Devil automated meteorological data collection field station

SENSORS

- Wind speed
- Wind direction
- Air temperature
- Rainfall
- Solar radiation

Figure 6. Turkey Creek automated meteorological data collection field station

Pueblo Airport, Butts Airfield (Fort Carson), and Colorado Springs Airport to permit development of a more accurate description of climatic conditions throughout the reservation. In addition to the two WES meteorological stations discussed above, a rain gage was installed with the water-quality sensors at Clover Ditch site 10 (Figure 2). As stated in paragraph 14, the Red Devil and Turkey Creek automated field stations were moved to new locations on 11 May 1976. These locations are the sediment basins that were being used by the WES to study the relations between precipitation, natural terrain and land-use factors, surface runoff, and sediment yield.* The relocated field stations (Figures 7 and 8) were used to record water-surface elevations in the sediment basins and meteorological data (see paragraph 11).

## Program Execution

17. The execution phase of the program included installing and maintaining the automated field stations. This work was accomplished cooperatively by WES and DFAE (Fort Carson) personnel. DFAE personnel routinely checked the performance of the field stations and maintained the water-quality sensors at Clover Ditch sites 6 and 10. WES personnel made periodic visits (4- to 6-week intervals) to the sites to perform routine maintenance and make necessary equipment repairs. The program was conducted from approximately 20 November 1975 to 20 April 1977 and is continuing. It has resulted in the accumulation of a considerable amount of data. Data collection periods and sampling intervals are listed by cassette tape numbers in the following tabulation.

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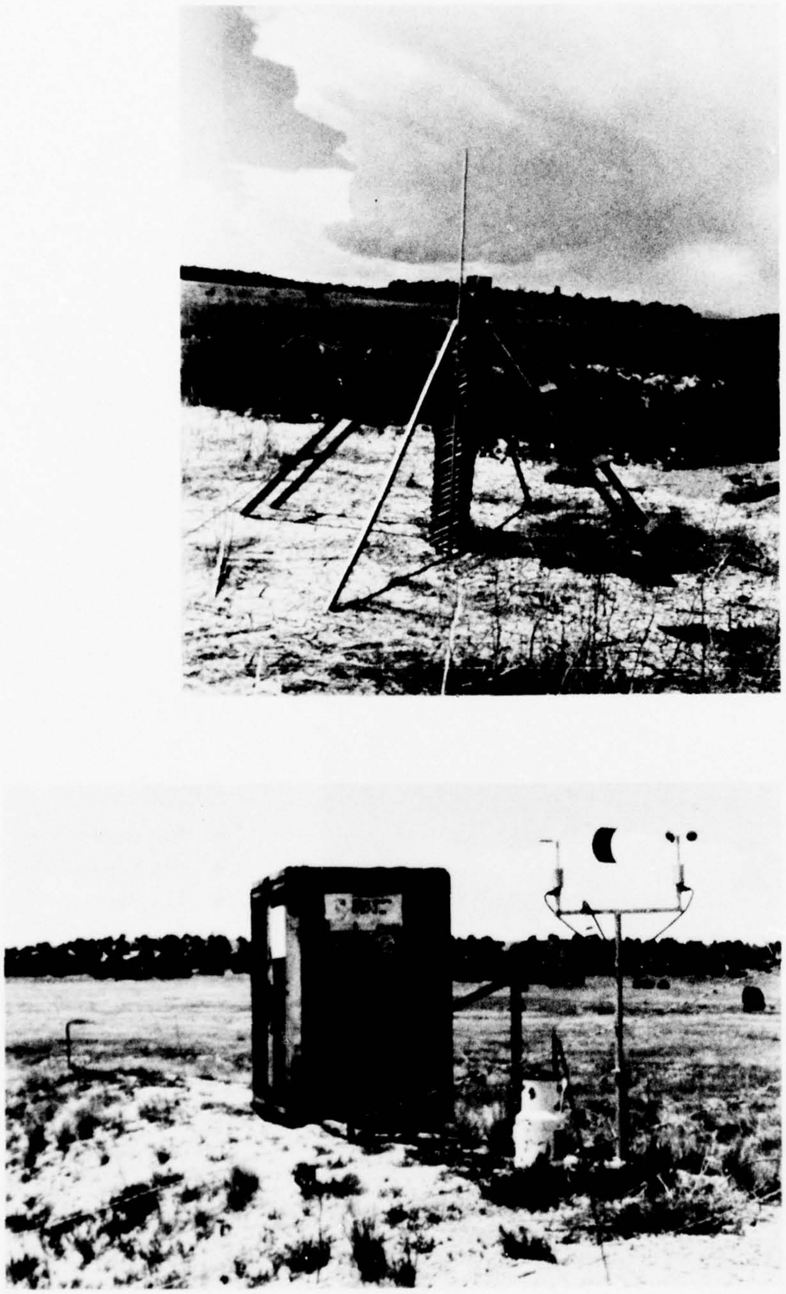
* Keown and West, op. cit.

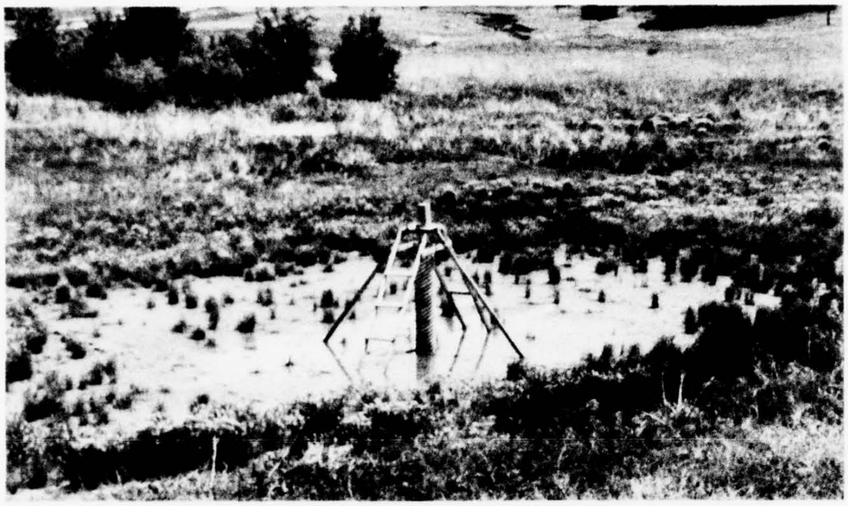


● Water stage sensor

SENSORS

- Wind speed
- Wind direction
- Air temperature
- Solar radiation
- Rainfall

Figure 7. Automated field station at Red Devil watershed sediment basin



● Water stage sensor

SENSORS

- Wind speed
- Wind direction
- Air temperature
- Solar radiation
- Rainfall

Figure 8. Automated field station at Turkey Creek watershed sediment basin

| Tape No. | Data Collection Period* | Sampling Interval, min |
|---|---|---|
| | Red Devil Station | |
| 1 | 20 Nov 75-10 Dec 75 | 60 |
| 2 | 11 Dec 75-16 Jan 76 | 60 |
| 3 | 16 Jan 76- 5 Feb 76 | 60 |
| 4 | 5 Feb 76- 2 Mar 76 | 60 |
| 5 | 2 Mar 76-24 Mar 76 | 60 |
| 6 | 25 Mar 76-19 Apr 76 | 60 |
| 7 | 21 Apr 76-12 May 76 | 60 |
| | Red Devil Sediment Basin | |
| 8 | 14 May 76-23 Jun 76 | 60 |
| 9 | 24 Jun 76- 4 Aug 76 | 60 |
| 10 | 4 Aug 76- 9 Sep 76 | 60 |
| 11 | 9 Sep 76-14 Oct 76 | 60 |
| 12 | 18 Nov 76-16 Dec 76 | 60 |
| 13 | 16 Dec 76-27 Jan 77 | 60 |
| 14 | 18 Feb 77-17 Mar 77 | 60 |
| 15 | 18 Mar 77-20 Apr 77 | 60 |
| | Turkey Creek Station | |
| 1 | 20 Nov 75- 3 Dec 75 | 60 |
| 2 | 10 Dec 75-27 Dec 75 | 60 |
| 3 | 15 Jan 76-22 Jan 76 | 60 |
| 4 | 5 Feb 76- 9 Feb 76 | 60 |
| 5 | 3 Mar 76-24 Mar 76 | 60 |
| 6 | 24 Mar 76-21 Apr 76 | 60 |
| 7 | 21 Apr 76-11 May 76 | 60 |
| | Turkey Creek Sediment Basin | |
| 8 | 12 May 76-24 Jun 76 | 60 |
| 9 | 25 Jun 76- 4 Aug 76 | 60 |
| 10 | 4 Aug 76- 7 Sep 76 | 60 |
| 11 | 9 Sep 76- 7 Oct 76 | 60 |
| 12 | 18 Nov 76-16 Dec 76 | 60 |
| 13 | 18 Feb 77-18 Mar 77 | 60 |
| 14 | 18 Mar 77-20 Apr 77 | 60 |

(Continued)

* Field station malfunctions resulted in some losses of data on all sensors during the study, and these losses of data are indicated by gaps in the data collection periods for each station. For example, at the Turkey Creek Station, there is a gap between 3 and 10 December 1977 indicating a loss of data for a 7-day period.

| Tape No. | Data Collection Period | Sampling Interval, min |
|---|---|---|
| | Clover Ditch Station Site 10 | |
| 1** | 6 Feb 76- 2 Mar 76 | 30 |
| 2 | 2 Mar 76-24 Mar 76 | 30 |
| 3 | 25 Mar 76- 7 Apr 76 | 30 |
| 4 | 13 May 76-21 Jun 76 | 30 |
| 5 | 24 Jun 76-25 Jul 76 | 30 |
| 6 | 11 Aug 76- 8 Sep 76 | 60 |
| 7 | 9 Sep 76-13 Oct 76 | 60 |
| 8 | 13 Oct 76-17 Nov 76 | 60 |
| 9 | 18 Nov 76-15 Dec 76 | 60 |
| 10 | 15 Dec 76-27 Jan 77 | 60 |
| 11 | 27 Jan 77-15 Feb 77 | 60 |
| 12 | 17 Feb 77-19 Mar 77 | 60 |
| 13 | 19 Mar 77-19 Apr 77 | 60 |
| | Clover Ditch Station Site 6 | |
| 1 | 13 May 76-22 Jun 76 | 30 |
| 2 | 25 Jun 76- 5 Aug 76 | 30 |
| 3 | 5 Aug 76- 8 Sep 76 | 60 |
| 4 | 9 Sep 76-13 Oct 76 | 60 |
| 5 | 14 Oct 76-16 Nov 76 | 60 |
| 6 | 17 Nov 76-15 Dec 76 | 60 |
| 7 | 15 Dec 76-16 Jan 77 | 60 |
| 8 | 27 Jan 77-15 Feb 77 | 60 |
| 9 | 17 Feb 77-19 Feb 77 | 60 |
| 10 | 19 Mar 77-19 Apr 77 | 60 |

** No valid data were obtained prior to 6 February 1976 as a result of equipment malfunctions.

Water-quality data were also collected manually at Clover Ditch site 6 between 1000 and 1400 hr on 20 November 1975, 11 December 1975, 16 January 1976, and 8 February 1976, prior to establishing the automated field station there on 12 May 1976 (see paragraph 13).

Performances of
field stations and sensors

18. The four field stations that were established for collecting meteorological, hydrologic, and water-quality data at Fort Carson, Colorado, performed very well considering the fact that they were not continuously attended; however, some equipment failures, malfunctions, and site related problems did result in losses of data during the period

of data collection. The performances of the field stations are discussed in the following paragraphs.

19. The groups of environmental sensors, which were installed at each of the two meteorological stations and the two water-quality field stations, acquired data from 20 November 1975 through 22 April 1977. However, on several occasions during this time, the field stations had malfunctions that resulted in no data being collected. These dates are indicated by gaps in the data collection periods listed in paragraph 17. The performance data for the field stations are summarized as follows:

| Field Station | Scheduled Number of Hours of Data Collection from 20 Nov 75 to 22 Apr 77 | Total Time Field Station Collected Data: Hours | Total Time Field Station Collected Data: Percent of Total Time |
|---|---|---|---|
| Red Devil and Red Devil Sediment Basin | 12,408 | 10,968 | 88 |
| Turkey Creek and Turkey Creek Sediment Basin | 12,408 | 8,352 | 67 |
| Clover Ditch Site 6 | 8,232 | 7,224 | 88 |
| Clover Ditch Site 10 | 12,384 | 9,168 | 74 |

The above data reflect only the fact that some type of environmental data was recorded by the field station(s), and what is missing at this point is an indication of the "error rate" or the amount of recorded data for the different sensors that were considered to be invalid due to whatever cause, such as sensor malfunction or failure, sensor calibration problems, power supply problems (i.e. low voltage), and contaminated water-quality probes.

20. For the purpose of evaluating field station and sensor performance, a satisfactory hourly record for a field station was considered to be one in which the data for 75 percent of the sensors were reliably recorded. The performances of the various field stations and sensors are summarized below in terms of the error rate and major types of equipment malfunctions and site related problems. The error rate in percent was computed by the following equation:

$$\frac{\text{Number of hours deployed - number of satisfactory hourly records}}{\text{Number of hours deployed}} \times 100$$

The error rates and primary causes for invalid data for each of the four stations are tabulated as follows:

| Field Station | Error Rate % | Primary Reasons for Invalid Data Ranked in Order of Occurrence |
|---|---|---|
| Red Devil and Red Devil Sediment Basin | 8 | (1) Recorder power supply failure (low voltage)<br>(2) Field station timer failure (improper timing sequence)<br>(3) High winds (>80 mph) caused damage to field stations and sensors |
| Turkey Creek and Turkey Creek Sediment Basin | 4 | (1) Field station timer failure (improper timing sequence)<br>(2) Cassette tape transport failure (improper contact of recording heading with magnetic tape)<br>(3) Sensor calibrations (solar-radiation, water level) |
| Clover Ditch Site 6 | 19 | (1) Contaminated probes (pH, D.O., conductivity)<br>(2) Damaged pH and D.O. probes<br>(3) Power supply failure (low voltage) for water-quality probes* |
| Clover Ditch Site 10 | 14 | (1) Contaminated probes (pH, D.O., conductivity)<br>(2) Damaged pH and D.O. probes (caused by high flows and debris)<br>(3) Field station timer failure (improper timing sequence) |

* This problem occurred prior to installation of a new power system (see paragraph 23).

Maintenance guide-
lines for the sensors

21. To ensure the accurate recording of water-quality data, maintenance guidelines for the sensors were developed and put into practice at Clover Ditch. These guidelines required semiweekly inspection of the probes. The maintenance after inspection depended on the in situ characteristics of water that was being monitored and the frequency and duration of local rainfall and surface runoff and debris carried by the stream.

22. The on-site maintenance procedures developed for the water-quality sensor packages (pH, conductivity, D.O., and water temperature) included servicing the probes on a weekly basis unless it was determined from the semiweekly inspection visits that the probes had been contaminated or damaged by increased surface runoff or debris carried by the stream. If the probes were determined to be working unsatisfactorily, maintenance was performed at that time. Maintenance and servicing of the probes during each data collection period were performed by Fort Carson Facilities Engineering personnel; WES personnel performed the servicing and maintenance of the probes at the time of each monthly visit to the stations.

23. At the start of the data collection work (20 November 1975), the WES used a 96 amp-hr wet-cell battery to provide power for operation of the water-quality probes. This, however, did not prove to be an adequate source of power, and as a result, a new power system consisting of a lead-calcium wet-cell battery and a specially designed solar panel (Appendix A, Figure A11) was obtained and installed at site 10 on 3 August 1976 and at site 6 on 18 November 1976. This power system has proven to be a far superior system, and no power problems have occurred with the water-quality probes since its installation.

## Data Reduction and Presentation

24. The third phase of the program involved data reduction and presentation. The cassette tapes with the recorded environmental data

were gathered at the end of each data collection period and taken to the WES for data translation, processing, and display. A 16K-memory PDP-15/30* digital system was used to process and display the data. A major step in this procedure involved checking the data for validity and accuracy and deleting those parameter values that were found to be in error. The final data were furnished to Fort Carson after each period of collection and, therefore, are not included in this report. However, the data are on file at the WES and at Fort Carson and are available on loan from the WES.**

25. Each parameter measured by the automated field station at Fort Carson has been output in tabular and graphic formats as described below:

a. Tabular data. Tabulations were produced for all sensors for each 30- or 60-min sampling interval used. One line of data in the computer printout represents one sampling interval of data collection. Table 1 is an example of the tabular data output for Red Devil meteorological field station for the period 2-24 March 1976.

b. Graphic data. The data were also produced in three different graphic formats. The first format includes a line plot (Figures 9-15) and a bar graph (Figure 16) that depict the individual parameter values for each respective sampling interval. These graphs contain data for a 7-day period. The second format is a line plot (Figure 17) that shows the maximum, average, and minimum measured sample values for a parameter throughout the data collection period. For example, the maximum, minimum, and average air temperatures measured at 1200 hr were 70.5°, 26.6°, and 52°F, respectively. The third graphic format is a wind rose (Figure 18) that depicts the percentage of the time the wind blows from each of eight directions: north, northeast, east, southeast, south, southwest, west, and northwest. Each direction includes all recorded hourly wind directions in a band 22.5 deg on both sides of the principal direction.

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* Digital Equipment Corporation, Maynard, Massachusetts.

** Contact: Commander and Director, U. S. Army Engineer Waterways Experiment Station, ATTN: WESFE, Vicksburg, Miss. 39180.

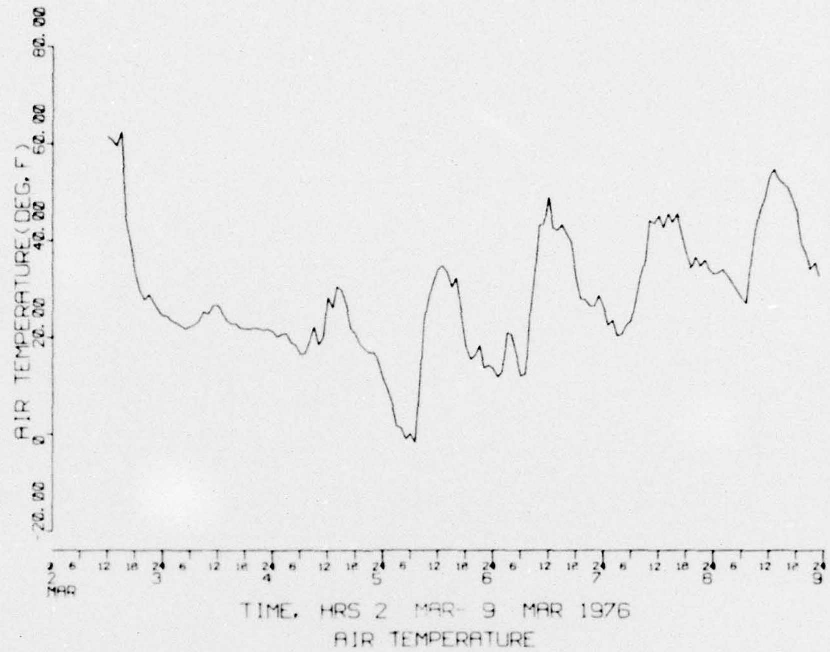


Figure 9. Line plot of air temperature versus time for 7 days, Red Devil station, Fort Carson, Colorado

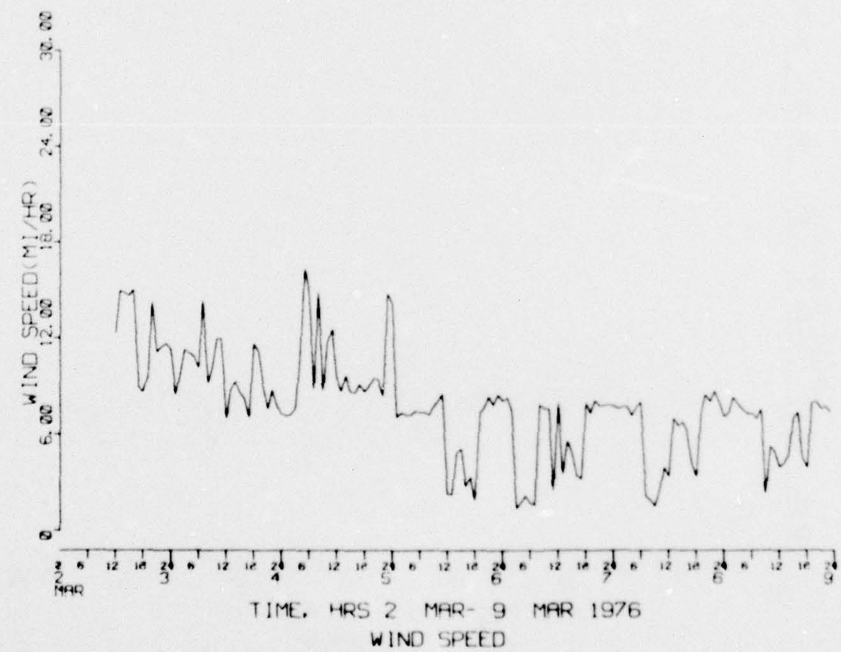


Figure 10. Line plot of wind speed versus time for 7 days, Red Devil station, Fort Carson, Colorado

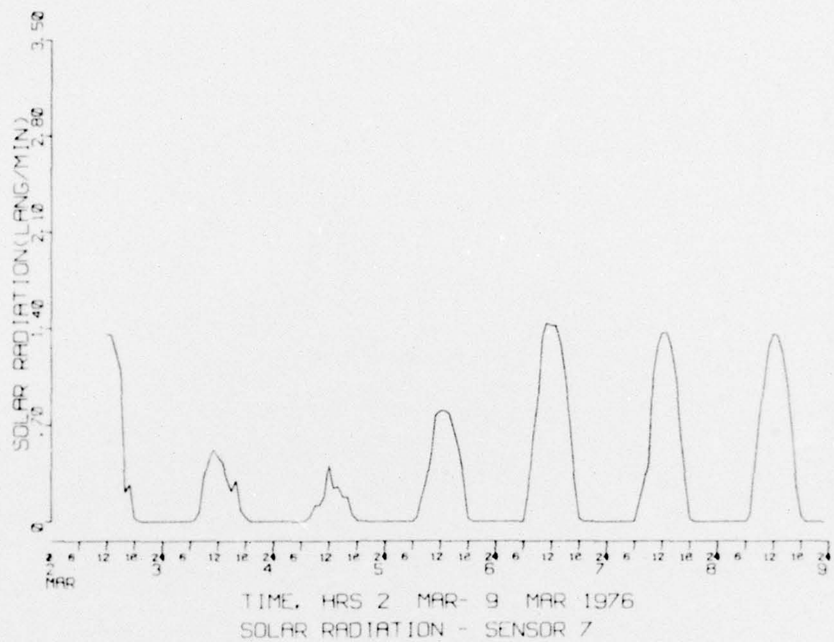


Figure 11. Line plot of solar radiation versus time for 7 days, Red Devil station, Fort Carson, Colorado

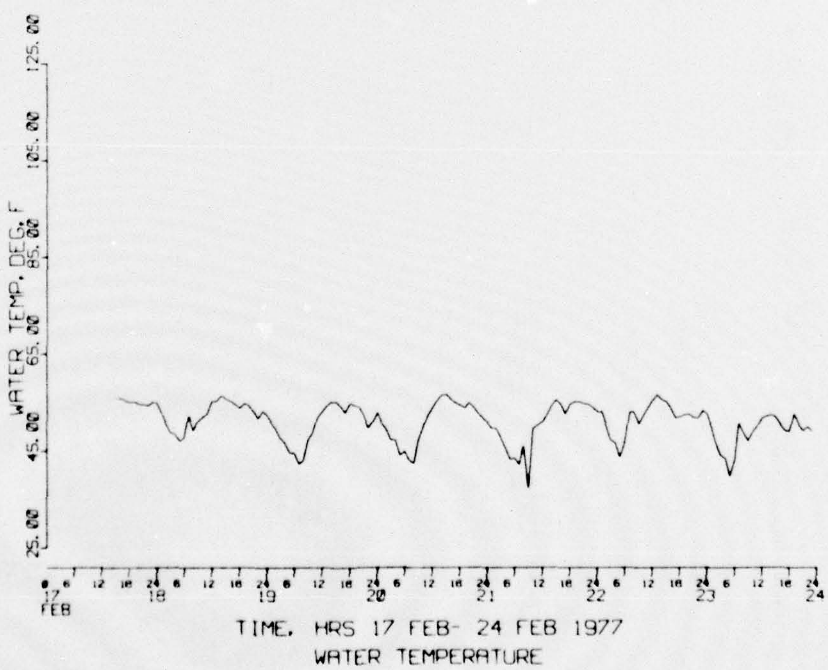


Figure 12. Line plot of water temperature versus time for 7 days, Clover Ditch station (site 6), Fort Carson, Colorado

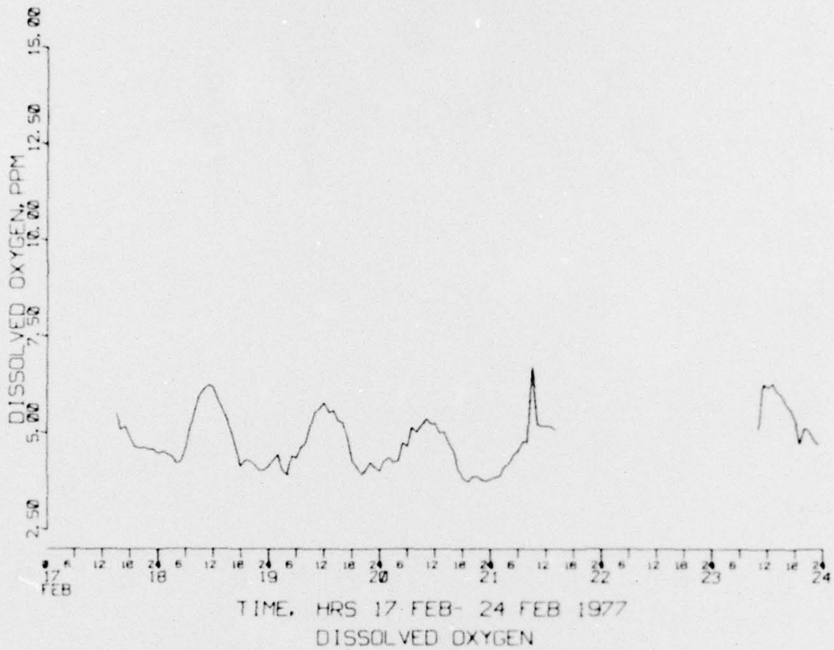


Figure 13. Line plot of D.O. versus time for 7 days, Clover Ditch station (site 6), Fort Carson, Colorado

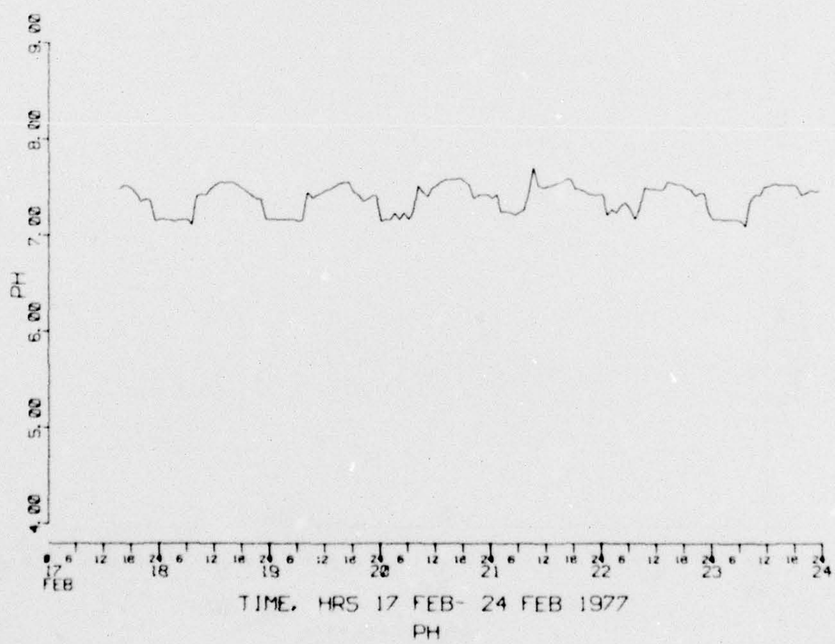


Figure 14. Line plot of pH versus time for 7 days, Clover Ditch station (site 6), Fort Carson, Colorado

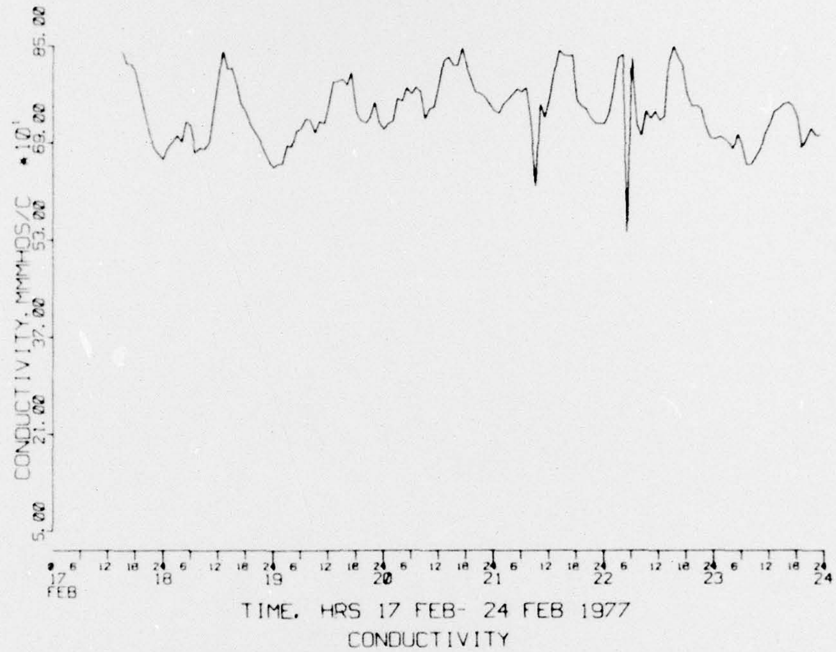


Figure 15. Line plot of conductivity versus time for 7 days Clover Ditch station (site 6), Fort Carson, Colorado

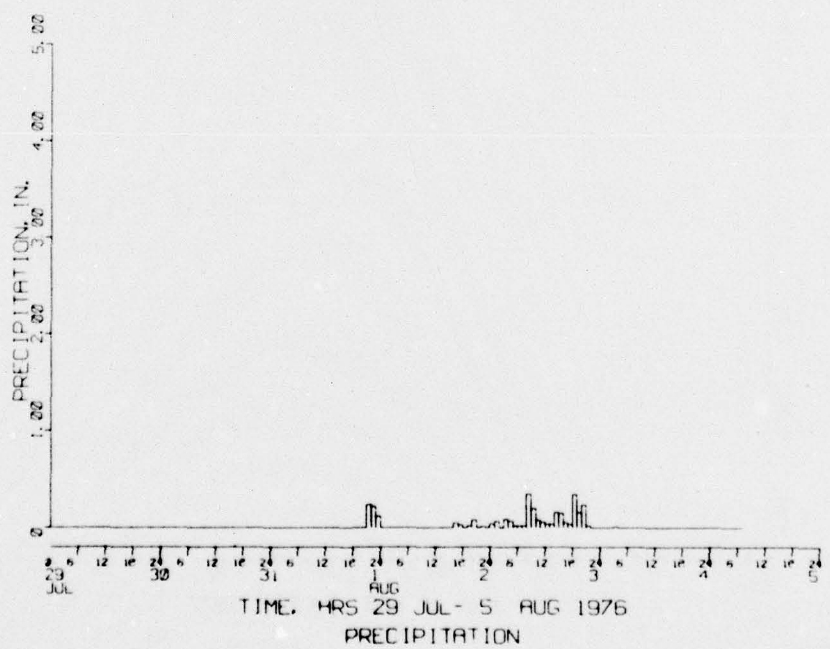


Figure 16. Bar graph of precipitation versus time for a period of 7 days, Red Devil station, Fort Carson, Colorado

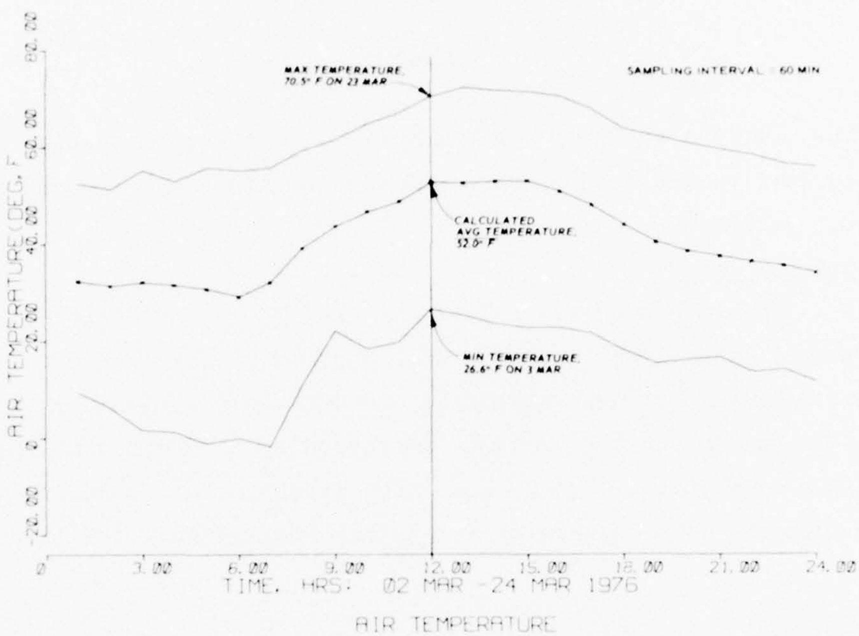


Figure 17. Line plot of the maximum, average, and minimum 24-hr values for air temperature during a 22-day (2-24 March 1976) record period, Red Devil station, Fort Carson, Colorado,

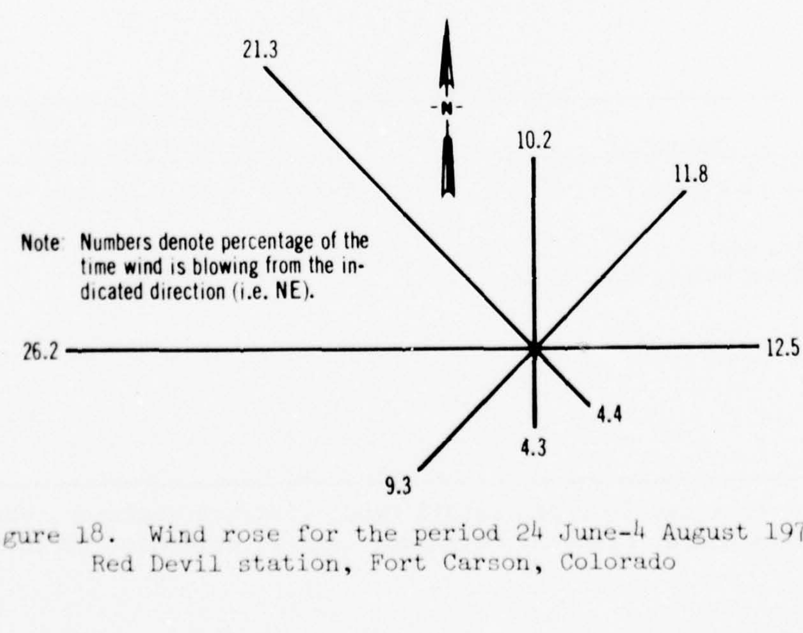


Figure 18. Wind rose for the period 24 June-4 August 1976, Red Devil station, Fort Carson, Colorado

## PART III: ANALYSES AND RECOMMENDATIONS

### Analyses

26. Limited analyses were made of the environmental data collected on water quality and meteorology, and the results are discussed in the following paragraphs.

Water-quality data

27. The water-quality values obtained by the automated field stations and manually by the WES field teams were compared with the State of Colorado Effluent Standards and Class B-2 Stream Standards, as well as the parameter value ranges preferred by the important animals that could inhabit the streams near Fort Carson, i.e. Fountain Creek. These parameter value standards and animal requirements are listed below:

Effluent Standards

| Parameter | State of Colorado Effluent Standards* |
|---|---|
| Water temperature, °F | None |
| pH | 6-9 |
| D.O., ppm | >2 |
| Conductivity, μmhos/cm | None |

Stream Standards

| Parameter | State of Colorado Class B-2 Stream Standards* |
|---|---|
| Water temperature, °F | Max 90; hourly change of 5°F |
| pH | 6-9 |
| D.O., ppm | >5 |
| Conductivity, μmhos/cm | None |

* Data obtained from Mr. Derald Land, District Engineer, Water-Quality Board, State of Colorado, Denver, Colorado 80220.

Animal Long-Duration Preferred Standards*

| Animals | D.O. ppm | pH | Temperature °F | Turbidity ppm |
|---|---|---|---|---|
| Warm-water fish (bass) | >4 | 5.5-9.5 | 32-90 | 60 |
| Cold-water fish (trout) | >6.5 | 6.5-8.5 | 32-65 | 60 |
| Crustacean (crayfish) | >3 | 4-9 | 32-90 | |
| Insect (caddis fly larva) | >1 | 3-9 | 32-90 | 10-100 |
| Mollusk (clam) | >1 | 5-9 | 32-90 | |

* Data obtained from Dr. J. M. Fitzsimons, Department of Zoology and Physiology, Louisiana State University, Baton Rouge, Louisiana.

28. Table 2 contains the monthly average values and ranges for D.O., water temperature, pH, and conductivity for sites 6 and 10 on Clover Ditch (Figure 2). The monthly average values and ranges were calculated for the total number of hourly records obtained for each month. Figure 19 illustrates typical diurnal fluctuations in the water-quality parameters for a winter day (8 February 1976) and a summer day (14 August 1976). The data presented in Table 2, together with some general observations, are discussed below.

29. Dissolved oxygen. The average values for D.O. calculated for site 6 were always above the State of Colorado Class B-2 Stream Standard of >5 ppm, whereas at site 10 the average values of D.O. were below the standard except for the months of October and November 1976.

30. The maximum measured D.O. values usually occurred between 1000 to 1400 hr; the minimum D.O. values, at about 2200 hr. The measured D.O. values at both sites were always above 1.7 ppm. The maximum and minimum summer D.O. values occurred about the same time of day as those observed during the winter months. However, the D.O. values obtained during the summer months were more erratic from day to day than those measured during the winter months. Also, the diurnal range was more variable and often larger. For example, at the end of summer the D.O. values occasionally ranged from greater than 10 ppm to 2.5 ppm.

31. Data on D.O. were analyzed to determine the total time the recorded values were above and below the State standard of >5 ppm.

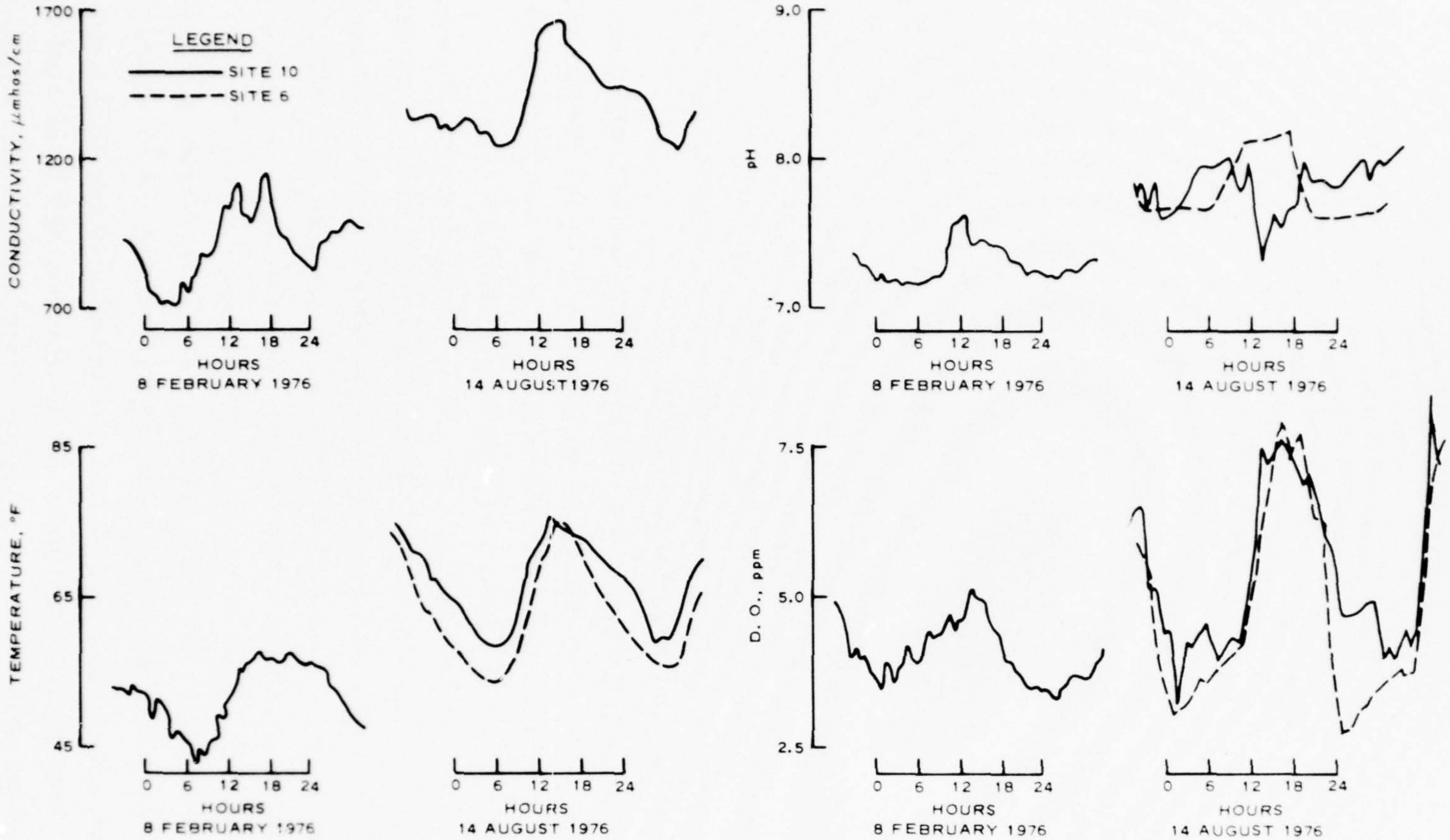


Figure 19. Water-quality parameter values for 8 February and 14 August 1976, Clover, Ditch, sites 6 and 10

These results, presented in Table 3, show that at site 10 the D.O. had more hours below the standard than above for all months except October and November; whereas at site 6 (the site that is upstream from the point where the effluent from the sewage treatment plant enters Clover Ditch) six of the nine months showed more hours above the standard.

32. Varying concentrations and the length of exposure to a given D.O. concentration influence the presence and abundance of aquatic animal species. To evaluate the impact of the frequency of occurrence above and below the standard D.O. concentration of >5 ppm, the time durations of all completed events* were tabulated and then assigned categories of ≤1/2, ≤6, ≤12, ≤18, ≤24, ≤72, or >72 hr. The cumulative percentage of the total number of events was then plotted as a function of number of events assigned to each category (Figure 20). The relatively high number

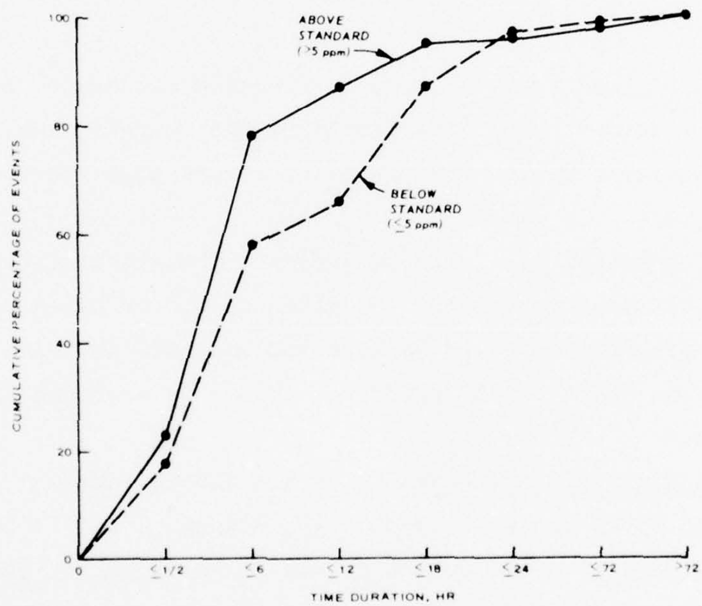


Figure 20. Cumulative percentage of events of D.O. for different time durations above and below the Colorado Class B-2 Stream Standard at site 10, Fort Carson, Colorado

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* A completed event is defined as that time period when the recorded D.O. becomes >5 ppm until the time it becomes ≤5 ppm, or that time period when the recorded D.O. becomes ≤5 ppm until the time it becomes >5 ppm.

of occurrences above and below the standard of >5 ppm of short duration ($\leq$12 hr) is due to the diurnal cycle of D.O. that relates to water temperature fluctuations and photosynthesis-respiration relations.

33. Water temperature. The water temperature in Clover Ditch was warmer at site 10 than at site 6 (Table 2b). The largest difference in the monthly average temperatures at the two sites occurred after October, during the winter months of November, December, and January, and ranged from 12° to 19°F. The monthly average temperatures and the maximum occurring values were within the State standard for maximum temperature of 90°F. The average hourly change in temperature at the two sites varied between 1.1 and 2.1°F (Table 4) and is also within the State standard of 5°F.

34. pH. The water in Clover Ditch showed little variation in pH throughout the data collection period (Table 2c). The monthly average pH value at site 10 was between 7.4 and 8.0 but at site 6 it was somewhat higher, ranging from 7.6 to 8.1. These measurements are all within the State standard of 6-9. The limits of the range of variation in pH summarized in Table 2c for the period of record also are within the State standard.

35. Conductivity. Table 2d presents the electrolytic conductivity of the water as measured at the two sites on Clover Ditch. At site 10, the monthly average value was between 480 and 1020 μmhos/cm and at site 6, between 521 and 1066 μmhos/cm. There is no State standard for conductivity.

36. Additional water-quality data. Manual sampling (profiling) was conducted at 10 sites (1 through 10, Figures 2 and 21) along Clover Ditch during daylight (≈1000-1400 hr) on 25 March 1976. The data that were obtained are plotted in Figure 21. The impact of the sewage treatment effluent (data from site 5) is reflected by a significant increase in water temperature and a decrease in D.O. at the downstream sites (sites 7, 10, 9, and 8). This is not surprising considering the high-temperature and low-D.O. levels of the sewage effluent (site 5) and the normally very small flow in Clover Ditch. On 25 March 1976, the water in Clover Ditch was very low, as the following tabulation shows:

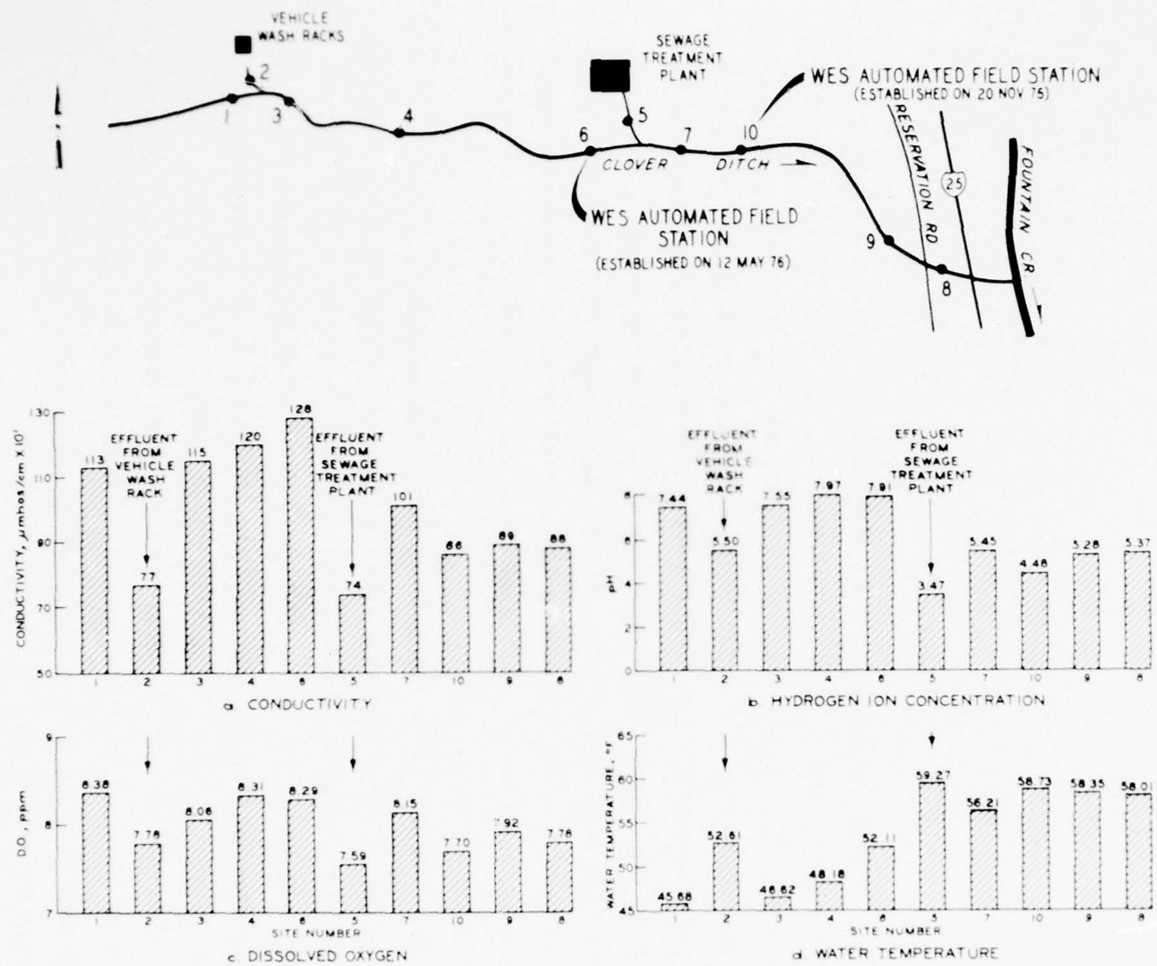


Figure 21. Data obtained on water quality in Clover Ditch and incoming effluent sources on 25 March 1976

| Site | Bottom Width of Channel ft | Depth of Channel ft | Water Width at Time of Measurement ft | Water Depth at Time of Measurement ft |
|---|---|---|---|---|
| 1 | 26.0 | 7.0 | 3.3 | 0.82 |
| 2 | 3.3 | 3.0 | 3.3 | 0.66 |
| 3 | 10.0 | 6.0 | 9.2 | 1.97 |
| 4 | 23.0 | 8.0 | 6.6 | 0.49 |
| 5 | 10.0 | 7.0 | 9.8 | 2.51 |
| 6 | 29.6 | 10.0 | 4.9 | 0.82 |
| 7 | 26.2 | 9.0 | 6.6 | 0.66 |
| 8 | 6.6 | 6.0 | 6.6 | 0.98 |
| 9 | 6.6 | 6.0 | 6.7 | 0.82 |
| 10 | 8.2 | 5.0 | 8.2 | 0.85 |

37. Figure 22 compares daytime measurements of water quality taken at Clover Ditch sites 6 and 10 on 20 November 1975, 11 December 1975, 16 January 1976, and 8 February 1976. Site 6 is located approximately 100 m upstream from the point where the effluent from the sewage treatment plant enters Clover Ditch; site 10 is located approximately 200 m downstream on Clover Ditch from the effluent entry point (Figure 2). The data presented in Figure 22 show that the sewage treatment plant effluent does not have a large effect on the pH and conductivity measurements but consistently increases the temperature and decreases the D.O. values in Clover Ditch.

38. According to the preliminary data analyses, the D.O. in the Clover Ditch flow at certain times during the 24-hr day is often lower than that preferred by some of the common freshwater aquatic animal species (see paragraph 27). However, further investigation is needed to identify the aquatic animal species, including benthic organisms, that inhabit Clover Ditch and Fountain Creek where it joins Clover Ditch. The presence or absence of certain species is an indication of the overall quality of streamflow. The potential hazards of the water quality to terrestrial wildlife and public health also should be investigated (see paragraph 45).

Meteorological data

39. Precipitation data. During this study precipitation data were obtained at the WES Red Devil, Turkey Creek, and Clover Ditch

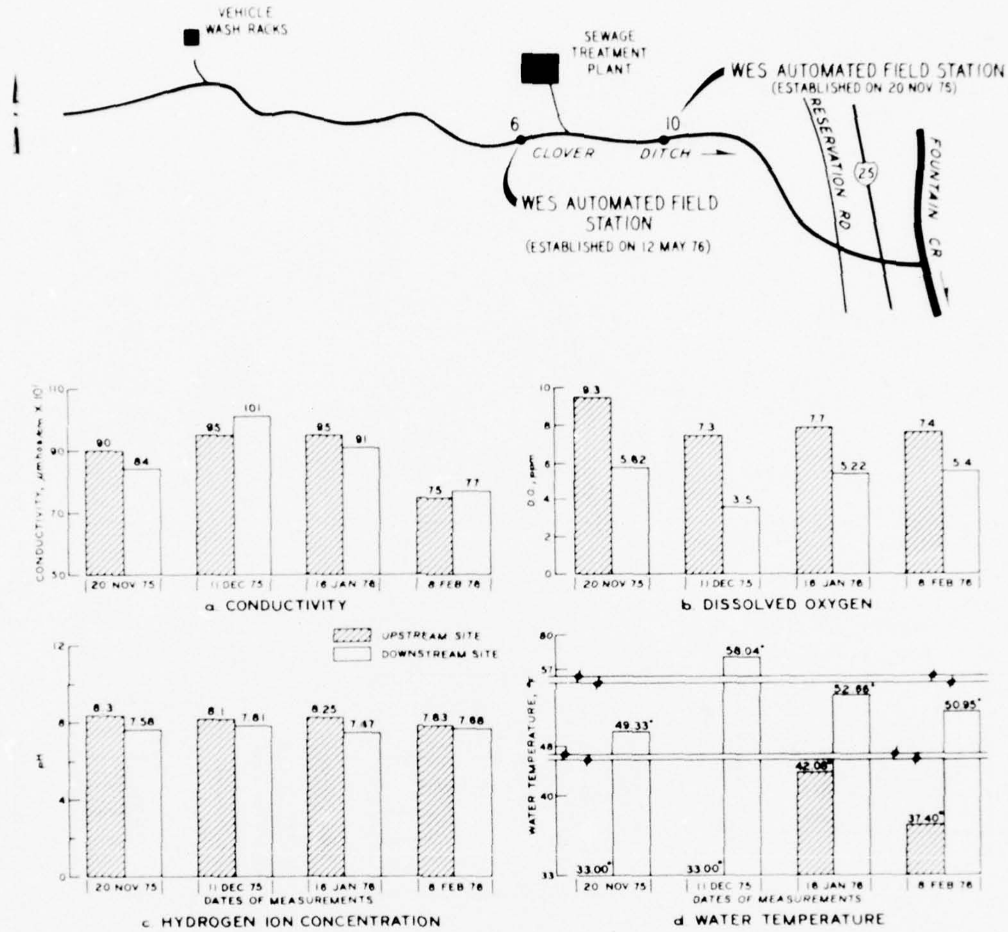


Figure 22. Data obtained at four different times showing the effects of sewage treatment plant effluent on water quality as measured in Clover Ditch sites 6 and 10

site 10 stations. Figure 23 presents the monthly averages of these data for 1976, with the precipitation data from the National Oceanic and Atmospheric Administration (NOAA) stations at Colorado Springs Airport, Pueblo Airport, and the Fort Carson Butts Airfield station. The plot shows that all of the stations except Butts Airfield received less than 1 in. per month of precipitation from October through March and that precipitation tended to increase gradually from March through September, with a reasonably pronounced wet season during July, August, and September. In general, a geographical trend can be observed in the

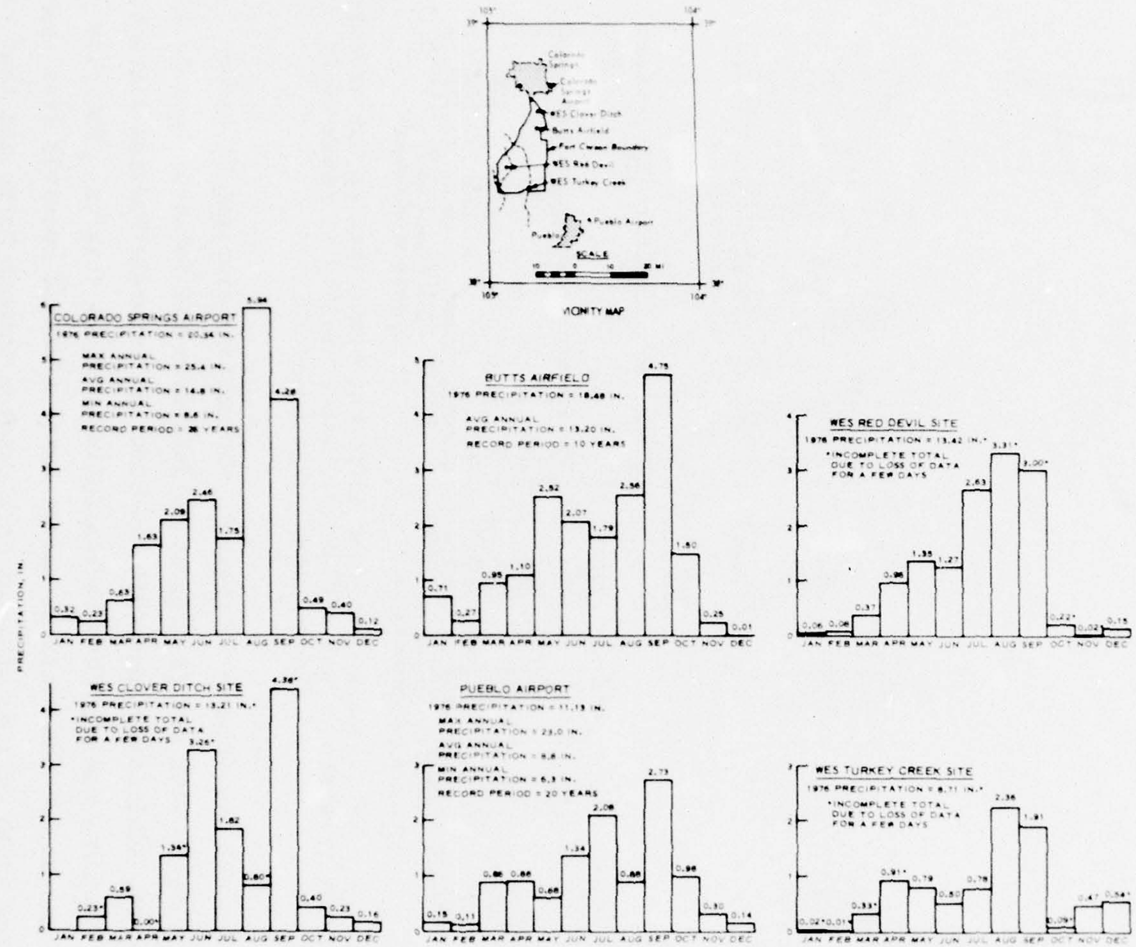


Figure 23. Precipitation data for six stations during 1976

rainfall measurements. The annual rainfall increases from south to north across the reservation. For example, the WES Red Devil and Turkey Creek stations show total precipitation amounts for 1976 of only 13.41 and 8.71 in.,* respectively; whereas, the precipitation values at Butts Airfield and Colorado Springs Airport were 18.48 and 20.34 in., respectively. Also, during 1976 the annual precipitation was above average when compared with past years of record (Table 5). Further discussion of precipitation amounts and distribution in the Fort Carson area is contained in Report 3 of this series.

40. Although these general trends are interesting, they do not provide data that can be of direct use to the Fort Carson natural resources management programs. Therefore, a more meaningful analysis and portrayal of the rainfall data for the reservation are needed. It is anticipated that long-term records from the nearby weather stations can be used to establish the frequency duration and intensity of rainfall for each month and that the areal distribution over the Fort Carson installation can be determined by correlating the individual storm durations and intensities from all of the available weather stations. Because of the mountainous topography that borders on Fort Carson and its effect on precipitation and wind currents, establishing the areal distributions of the various storms will not be straightforward. However, the data obtained by the three WES field stations during this study, in conjunction with other long-term meteorological data, should provide a more adequate picture of rainfall and wind conditions throughout the reservation.

41. Surface wind direction data. Wind roses (see paragraph 25) were prepared for the WES Red Devil and Turkey Creek stations for each period of data collection, as listed in paragraph 14, and were sent to Fort Carson periodically throughout the study. These data were used to prepare a summary of the predominant directions from which the surface wind was blowing for the period 20 November 1975 through 27 January 1977

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* These values represent incomplete totals for the year due to the loss of a few days' data.

(Table 6). In general, the surface winds for the period of December through mid-May blew generally from a south (S) to southeasterly (SE) direction, although at various times they varied significantly from the S-SE directions. During the period mid-May through November, which includes the high precipitation months of July, August, and September, the surface winds blew primarily from a westerly to northerly direction. However, these data should be analyzed in detail to provide areal distributions of the wind currents over the southern part of the reservation.

42. Surface wind speeds. The surface wind speed as measured at the Red Devil and Turkey Creek stations are summarized in Table 7 in terms of the average value and range. In general, the strongest surface winds occurred during the winter months of November through February reaching a high average of 12 mph in March 1976. The maximum hourly wind speed recorded at the Red Devil station was 30 mph and at Turkey Creek, 24 mph.

43. Solar radiation. The solar radiation as measured at the Red Devil and Turkey Creek field stations reached a high of approximately 1.73 Langley (Ly)/min during the summer months and averaged between 1.40 and 1.58 Ly/min (Table 8). The daily maximum reading usually occurred between 1200-1300 hr. During the winter months of November through February, the maximum radiation ranged between 0.82 and 1.28 Ly/min, with the maximum occurring during 1200-1300 hr. The winter average values were between 0.77 and 1.36 Ly/min.

44. Air temperatures. The measured air temperatures at the Red Devil and Turkey Creek sites were significantly different for some months (Table 9). The monthly average temperature during the winter months ranged from 48° to 60°F at Red Devil and from 29° to 50°F at Turkey Creek.

## Recommendations

45. Based on preliminary analysis of some of the water-quality and meteorological data collected during this study, the following work

is recommended to better aid Fort Carson in its long-range natural resource management programs:

- *a*. Analyze further the WES meteorological data collected during this study, together with data from nearby weather stations, to determine by statistical analysis the return frequency, duration, and intensity of seasonal rainfall that might be expected to occur in different geographical areas of the reservation, and to provide areal data on surface wind currents (speeds and directions) for the southern half of the installation.

- *b*. Study the WES water-quality data collected on Clover Ditch, together with data from nearby water-quality stations on Fountain Creek, to determine the effects of the surface waters in Clover Ditch on the aquatic life that would be expected to occur in Clover Ditch and Fountain Creek.

- *c*. Conduct additional long-term monitoring at Fort Carson with the WES automated field stations to provide the data needed to support a feasibility-type rangeland restoration program dealing with vegetation reestablishment, erosion control, and improvement of native wildlife habitats.

Table 1

Example of Tabular Output, Automated Field Station

RED DEVIL METEROLOGICAL STATION
MILITARY COORDINATES = 146536
FT CARSON COLORADO
MEASUREMENT INTERVAL: 60 MINUTES
RECORD PERIOD: 02 MAR - 24 MAR 1976

| DATE DA MO YR | SAMPLE TIME HR MN | PRECIP-ITATION IN. | WIND SPEED MI/HR | WIND DIRECTION DEG,N | AIR TEMPERATURE DEG,F | SOLAR RADIATION LANG/MIN | SOLAR RADIATION LANG/MIN |
|---|---|---|---|---|---|---|---|
| (SENSOR NO.) | | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 3 76 | | | | | | | |
| | 12* 0 | 0.00 | 12.39 | 108.0 | 61.5 | 1.29 | 1.36 |
| | 13* 0 | 0.00 | 15.01 | 168.5 | 60.6 | 1.26 | 1.35 |
| | 14* 0 | 0.00 | 14.85 | 155.0 | 59.5 | 1.14 | 1.23 |
| | 15* 0 | 0.00 | 14.71 | 89.5 | 62.4 | 1.00 | 1.09 |
| | 16* 0 | 0.00 | 15.07 | 315.5 | 44.6 | 0.20 | 0.21 |
| | 17* 0 | 0.00 | 8.94 | 334.0 | 39.4 | 0.27 | 0.27 |
| | 18* 0 | 0.00 | 8.68 | 325.5 | 33.4 | 0.02 | 0.02 |
| | 19* 0 | 0.00 | 9.64 | 0.0 | 29.5 | 0.00 | 0.00 |
| | 20* 0 | 0.00 | 14.25 | 5.5 | 27.7 | 0.00 | 0.00 |
| | 21* 0 | 0.00 | 11.15 | 104.0 | 28.8 | 0.00 | 0.00 |
| | 22* 0 | 0.00 | 11.49 | 58.5 | 27.0 | 0.00 | 0.00 |
| | 23* 0 | 0.00 | 11.68 | 44.0 | 25.5 | 0.00 | 0.00 |
| 3 3 76 | | | | | | | |
| | 0* 0 | 0.00 | 11.31 | 79.0 | 24.4 | 0.00 | 0.00 |
| | 1* 0 | 0.00 | 8.50 | 74.5 | 24.3 | 0.00 | 0.00 |
| | 2* 0 | 0.00 | 9.90 | 59.5 | 23.2 | 0.00 | 0.00 |
| | 3* 0 | 0.00 | 11.31 | 77.0 | 23.0 | 0.00 | 0.00 |
| | 4* 0 | 0.00 | 11.06 | 134.5 | 22.3 | 0.00 | 0.00 |
| | 5* 0 | 0.00 | 10.90 | 69.0 | 21.7 | 0.00 | 0.00 |
| | 6* 0 | 0.00 | 10.16 | 105.0 | 22.3 | 0.00 | 0.00 |
| | 7* 0 | 0.00 | 14.37 | 83.0 | 22.6 | 0.01 | 0.01 |
| | 8* 0 | 0.00 | 9.23 | 97.0 | 23.5 | 0.06 | 0.07 |
| | 9* 0 | 0.00 | 10.16 | 129.0 | 25.3 | 0.32 | 0.32 |
| | 10* 0 | 0.00 | 12.01 | 38.5 | 24.8 | 0.43 | 0.44 |
| | 11* 0 | 0.00 | 12.01 | 50.5 | 26.6 | 0.50 | 0.52 |
| | 12* 0 | 0.00 | 7.01 | 51.0 | 26.6 | 0.45 | 0.47 |
| | 13* 0 | 0.00 | 8.80 | 29.5 | 25.3 | 0.42 | 0.43 |
| | 14* 0 | 0.00 | 9.30 | | 23.5 | 0.29 | 0.30 |
| | 15* 0 | 0.00 | 8.63 | 0.0 | 22.8 | 0.21 | 0.22 |
| | 16* 0 | 0.00 | 8.23 | 17.0 | 22.8 | 0.29 | 0.30 |
| | 17* 0 | 0.00 | 7.08 | 16.0 | 21.9 | 0.08 | 0.08 |
| | 18* 0 | 0.00 | 11.69 | 0.0 | 21.7 | 0.02 | 0.03 |
| | 19* 0 | 0.00 | 11.18 | | 21.7 | 0.00 | 0.00 |
| | 20* 0 | 0.00 | 9.07 | 249.5 | 21.9 | 0.00 | 0.00 |
| | 21* 0 | 0.00 | 7.63 | 197.0 | 21.7 | 0.00 | 0.00 |
| | 22* 0 | 0.00 | 8.80 | 301.5 | 21.4 | 0.00 | 0.00 |
| | 23* 0 | 0.00 | 7.78 | 201.0 | 21.7 | 0.00 | 0.00 |
| 4 3 76 | | | | | | | |
| | 0* 0 | 0.00 | 7.30 | 233.0 | 21.2 | 0.00 | 0.00 |
| | 1* 0 | 0.00 | 7.16 | 243.5 | 20.1 | 0.00 | 0.00 |
| | 2* 0 | 0.00 | 7.26 | 203.0 | 20.7 | 0.00 | 0.00 |
| | 3* 0 | 0.00 | 7.63 | 282.0 | 20.8 | 0.00 | 0.00 |
| | 4* 0 | 0.00 | 10.80 | 0.0 | 18.9 | 0.00 | 0.00 |
| | 5* 0 | 0.00 | 16.35 | 59.0 | 18.3 | 0.00 | 0.00 |

Table 2

Monthly Average Values and Ranges of D.O., Water Temperature, pH, and Conductivity for Clover Ditch Sites 10 and 6*

| | Clover Ditch Site 10 | | | Clover Ditch Site 6 | | |
|---|---|---|---|---|---|---|
| Month | Total Hours of Valid Data | Average | Range | Total Hours of Valid Data | Average | Range |
| | | | a. Dissolved Oxygen, ppm | | | |
| Feb 76 | 575 | 3.0 | 1.7-5.0 | ** | ** | ** |
| Mar 76 | 527 | 4.0 | 2.0-6.0 | ** | ** | ** |
| Apr 76 | 153 | 3.5 | 2.5-5.5 | ** | ** | ** |
| May 76 | 155 | 3.5 | 2.5-5.0 | 370 | 7.0 | 3.0-9.5 |
| Jun 76 | 237 | 4.5 | 3.0-6.0 | 201 | † | † |
| Jul 76 | 356 | 5.0 | 2.5-7.5 | 628 | 5.5 | 3.0-8.0 |
| Aug 76 | 91 | 5.0 | 4.0-8.0 | 612 | 5.5 | 2.5-9.5 |
| Sep 76 | 266 | † | † | 602 | 6.0 | 2.5-9.5 |
| Oct 76 | 689 | 5.5 | 3.0-9.0 | 545 | 6.0 | 4.0-11.0 |
| Nov 76 | 700 | 6.0 | 3.0-9.0 | 445 | 6.0 | 3.0-10.5 |
| Dec 76 | 656 | 5.0 | 3.0-6.0 | 648 | 7.0 | 3.0-8.5 |
| Jan 77 | 308 | 4.3 | 3.0-7.0 | 214 | 6.5 | 3.0-8.5 |
| | | | b. Water Temperature, °F | | | |
| Feb 76 | 515 | 55 | 40-65 | ** | ** | ** |
| Mar 76 | 538 | 55 | 40-60 | ** | ** | ** |
| Apr 76 | 164 | 60 | 50-67 | ** | ** | ** |
| May 76 | 384 | 63 | 45-75 | 443 | 56 | 45-75 |
| Jun 76 | 454 | 65 | 60-75 | 535 | 62 | 50-75 |
| Jul 76 | 579 | 68 | 60-75 | 631 | 66 | 55-80 |
| Aug 76 | 438 | 68 | 60-75 | 674 | 65 | 55-75 |
| Sep 76 | 691 | 65 | 50-75 | 628 | 60 | 45-75 |
| Oct 76 | 728 | 60 | 45-70 | 572 | 52 | 40-67 |
| Nov 76 | 709 | 53 | 45-65 | 496 | 41 | 35-54 |
| Dec 76 | 731 | 49 | 40-55 | 661 | 36 | <32-42 |
| Jan 77 | 340 | 48 | 50-50 | 337 | 33 | <32-35 |

**(Continued)**

* Values for averages and ranges are based on the total number of hourly records of valid data obtained for each month.

** No data (field station was not established until 12 May 1976).

† Insufficient valid data for determining monthly average.

Table 2 (Concluded)

| Month | Clover Ditch Site 10: Total Hours of Valid Data | Clover Ditch Site 10: Average | Clover Ditch Site 10: Range | Clover Ditch Site 6: Total Hours of Valid Data | Clover Ditch Site 6: Average | Clover Ditch Site 6: Range |
|---|---|---|---|---|---|---|
| | | c. Hydrogen Ion Concentration, pH | | | | |
| Feb 76 | 516 | 7.4 | 6.7-7.5 | ** | ** | ** |
| Mar 76 | 504 | 7.6 | 6.8-7.9 | ** | ** | ** |
| Apr 76 | 168 | 7.7 | 7.5-8.0 | ** | ** | ** |
| May 76 | 373 | 7.7 | 7.2-8.1 | 391 | 8.1 | 7.5-8.6 |
| Jun 76 | 327 | 7.8 | 7.5-8.5 | 492 | 7.3 | 7.5-8.3 |
| Jul 76 | 525 | 8.0 | 7.8-8.4 | 628 | 7.8 | 7.2-8.2 |
| Aug 76 | 438 | 7.7 | 7.3-8.3 | 646 | 7.7 | 7.3-8.3 |
| Sep 76 | 479 | 7.6 | 7.0-8.0 | 591 | 7.6 | 7.3-8.2 |
| Oct 76 | 455 | 7.7 | 7.4-8.5 | 565 | 7.7 | 7.3-8.2 |
| Nov 76 | 573 | 7.9 | 7.7-8.3 | 432 | 7.9 | 7.4-8.2 |
| Dec 76 | 731 | 8.0 | 7.5-8.5 | 650 | 7.6 | 7.4-7.9 |
| Jan 77 | 434 | 8.0 | 7.7-8.3 | 352 | 7.7 | 7.4-7.9 |
| | | d. Conductivity, μmhos/cm | | | | |
| Feb 76 | 515 | 830 | 750-950 | ** | ** | ** |
| Mar 76 | 519 | 800 | 560-1100 | ** | ** | ** |
| Apr 76 | 164 | 1020 | 910-1110 | ** | ** | ** |
| May 76 | 405 | 860 | 330-1270 | 385 | 1066 | 341-1570 |
| Jun 76 | 386 | 840 | 400-1320 | 511 | 950 | 390-1450 |
| Jul 76 | 579 | 884 | 325-1450 | 670 | 703 | 424-946 |
| Aug 76 | 438 | 685 | 520-880 | 457 | 737 | 425-1335 |
| Sep 76 | 687 | 663 | 200-920 | 617 | 859 | 400-1880 |
| Oct 76 | 731 | 679 | 420-928 | 576 | 935 | 600-1260 |
| Nov 76 | 697 | 600 | 466-740 | 482 | 695 | 360-1108 |
| Dec 76 | 728 | 516 | 385-675 | 637 | 610 | 420-750 |
| Jan 77 | 466 | 480 | 280-565 | 332 | 521 | 450-624 |

** No data (field station was not established until 12 May 1976).

Table 3

Comparison of Sample Hours When the Dissolved Oxygen in Clover Ditch Was Above and Below the Type B-2 Stream Standards for Colorado

| Month | Site 10 | | Site 6 | |
|---|---|---|---|---|
| | Total Sample Hours Below Stream Standard (≤5 ppm) | Total Sample Hours Above Stream Standard (>5 ppm) | Total Sample Hours Below Stream Standard (≤5 ppm) | Total Sample Hours Above Stream Standard (>5 ppm) |
| Feb 76 | 2.5 | 572.5 | * | * |
| Mar 76 | 54.0 | 472.5 | * | * |
| Apr 76 | 17.5 | 135.0 | * | * |
| May 76 | 1.0 | 154.0 | 236.5 | 133.5 |
| Jun 76 | 104.0 | 133.0 | 135.5 | 65.5 |
| Jul 76 | 151.0 | 205.0 | 235.0 | 392.5 |
| Aug 76 | 33.0 | 58.0 | 335.0 | 277.0 |
| Sep 76 | 70.0 | 196.0 | 271.0 | 331.0 |
| Oct 76 | 476.0 | 210.0 | 35.0 | 510.0 |
| Nov 76 | 526.0 | 174.0 | 56.0 | 389.0 |
| Dec 76 | 197.0 | 459.0 | 13.0 | 635.0 |
| Jan 77 | 72.0 | 236.0 | 7.0 | 207.0 |
| Totals | 1704.0 | 3008.0 | 1324.0 | 2940.5 |
| | Combined Total = 4712.0 | | Combined Total = 4264.6 | |
| Percent of recorded time represented by the data | 19 | 34 | 18 | 41 |

* No data (field station was not established until 12 May 1976).

Table 4

Hourly Water Temperature Changes* at Sites 10 and 6 on Clover Ditch

| Month | Total Hours of Valid Data | Average Hourly Temperature Change at Site 10 °F | Total Hours of Valid Data | Average Hourly Temperature Change at Site 6 °F |
|---|---|---|---|---|
| Feb 76 | 515 | 1.5 | ** | ** |
| Mar 76 | 538 | 2.0 | ** | ** |
| Apr 76 | 164 | 1.5 | ** | ** |
| May 76 | 384 | 1.7 | 443 | 1.5 |
| Jun 76 | 454 | 1.6 | 535 | 1.5 |
| Jul 76 | 579 | 1.7 | 631 | 2.0 |
| Aug 76 | 438 | 2.1 | 674 | 2.0 |
| Sep 76 | 691 | 2.2 | 628 | 1.7 |
| Oct 76 | 728 | 2.1 | 572 | 1.5 |
| Nov 76 | 709 | 2.0 | 496 | 1.5 |
| Dec 76 | 731 | 1.7 | 661 | 1.5 |
| Jan 77 | 340 | 1.3 | 337 | 1.1 |

* In most cases, the hourly changes were a result of increasing temperatures, although changes were also observed when the temperature was decreasing. Most of the larger hourly temperature changes occurred between 0700 and 1000 and 1200 and 1500 hr.

** No data (field station was established at site 6 until 12 May 1976).

Table 5

Summary of Annual Precipitation Data for Stations in the Vicinity of Fort Carson from 1945-1976

| Station* | Annual Precipitation, in. | | | Number Years of Record |
|---|---|---|---|---|
| | Minimum | Average | Maximum | |
| Canon City | 5.11 | 12.43 | 23.49 | 31 |
| Colorado Springs | 14.84 | 17.01 | 19.18 | 2 |
| Colorado Springs Airport** | 8.59 | 14.86 | 25.63 | 28 |
| Fountain | 8.43 | 14.14 | 26.61 | 32 |
| Fountain (9 miles NE) | 8.99 | 13.36 | 24.35 | 11 |
| Penrose (3 miles NNW) | 4.70 | 12.33 | 20.11 | 28 |
| Pueblo (3 miles SW) | 8.25 | 12.36 | 15.57 | 9 |
| Pueblo (6 miles SSW) | 8.45 | 10.12 | 10.72 | 3 |
| Pueblo Airport** | 6.27 | 11.36 | 23.09 | 22 |
| Pueblo Army Depot | 5.72 | 10.47 | 16.16 | 17 |
| Pueblo Fire Station 2 | 8.85 | 12.21 | 15.51 | 6 |
| Pueblo Fire Station 5 | 13.05 | 15.08 | 17.93 | 4 |
| Pueblo Reservoir | 6.80 | 11.05 | 18.18 | 20 |
| Butts Airfield, Fort Carson | 8.69 | 12.87 | 19.07 | 7 |

* Precipitation measured hourly.

** Precipitation measured daily (once per 24 hr) at all stations, except Colorado Springs Airport and Pueblo Airport.

Table 6

Predominant Directions from Which the Surface Wind Was Blowing and the Percentage of Occurrence at Red Devil and Turkey Creek Stations

| Data Collection Periods | | | | | | |
|---|---|---|---|---|---|---|
| **Red Devil Station** | | | | | | |
| 20 Nov-10 Dec 75 (21 days) | 11 Dec 75-16 Jan 76 (37 days) | 16 Jan-5 Feb 76 (21 days) | 5 Feb-2 Mar 76 (25 days) | 2 Mar-24 Mar 76 (22 days) | 25 Mar-19 Apr 76 (26 days) | 21 Apr-12 May 76 (22 days) |
| W(27); NW(26) | S(15); NE(14) SE(14) | NE(20); E(15) | W(28); SW(25) | S(15); SE(14) | N(17); W(16) NE(15) | SE(17); S(14) NE(14) NW(14) |
| ← ↖ | ↓ ↗ ↘ | ↗ → | ← ↗ | ↓ ↘ | ↑ ← ↗ | ↘ ↓ ↗ ↖ |
| 14 May-23 Jun 76 (41 days) | 24 Jun-4 Aug 76 (40 days) | 8 Aug-9 Sep 76 (33 days) | 18 Nov-16 Dec 76 (28 days) | 16 Dec 76-27 Jan 77 (43 days) | | |
| NW(24); E(19) W(18) | W(25); NW(21) | NW(26); W(21) | N(27); SE(22) | SE(30); N(23) | | |
| ↖ → ← | ← ↖ | ↖ ← | ↑ ↘ | ↘ ↑ | | |
| **Turkey Creek Station** | | | | | | |
| 20 Nov-3 Dec 75 (14 days) | 10 Dec-27 Dec 75 (18 days) | 15 Jan-22 Jan 76 (8 days) | 5 Feb-9 Feb 76 (5 days) | 3 Mar-24 Mar 76 (21 days) | 24 Mar-21 Apr 76 (28 days) | 21 Apr-11 May 76 (21 days) |
| E(24); NE(20) | SE(20); S(18) | SE(25); S(22) | E(23); NE(21) | SE(21); E(21) | S(25); E(18) | SW(29); S(19) |
| → ↗ | ↘ ↓ | ↘ ↓ | → ↗ | ↘ → | ↓ → | ↙ ↓ |
| 14 May-23 Jun 76 (41 days) | 25 Jun-4 Aug 76 (40 days) | 4 Aug-7 Sep 76 (34 days) | 18 Nov-16 Dec 76 (28 days) | 16 Dec 76-27 Jan 77 (43 days) | | |
| No data | NW(23); E(18) W(17) | NE(27); W(20) | NW(26); W(25) | No data | | |
| | ↖ → ← | ↗ ← | ↖ → | | | |

Note: Arrow denotes direction from which wind is blowing.

Table 7

Wind Speeds for Red Devil and Turkey Creek

| Month | Wind Speed, mph: Total Hours of Valid Data | Average | Range | Total Hours of Valid Data | Average | Range |
|---|---|---|---|---|---|---|
| | Red Devil Station* | | | Turkey Creek Station** | | |
| Nov 75 | 248 | 11 | 6-23 | 250 | 10 | 3-24 |
| Dec 75 | 709 | 11 | 8-22 | 441 | 11 | 2-23 |
| Jan 76 | 735 | 10 | 5-15 | 154 | 10 | 7-16 |
| Feb 76 | 670 | 10 | 0-30 | 104 | 10 | 2-18 |
| Mar 76 | 706 | 11 | 1-23 | 659 | 12 | 0-24 |
| Apr 76 | 666 | 10 | 0-11 | 718 | 6 | 0-15 |
| | Red Devil Sediment Basin* | | | Turkey Creek Sediment Basin* | | |
| May 76 | 448 | 7 | 1-11 | 468 | 5 | 1-13 |
| Jun 76 | 696 | 10 | 0-15 | 696 | † | † |
| Jul 76 | 744 | 9 | 1-14 | 743 | † | † |
| Aug 76 | 740 | 10 | 1-11 | 742 | † | † |
| Sep 76 | 720 | 9 | 0-10 | 686 | 5 | 0-9 |
| Oct 76 | 325 | 8 | 0-10 | 145 | 6 | 1-10 |
| Nov 76 | 324 | 9 | 0-10 | 270 | 5 | 0-13 |
| Dec 76 | 741 | 7 | 0-11 | 354 | 4 | 0-10 |
| Jan 77 | 631 | 9 | 0-11 | † | † | † |
| Feb 77 | 255 | 8 | 0-11 | 278 | 7 | 1-15 |
| Mar 77 | † | † | † | 744 | 9 | 0-16 |

* Wind speeds were measured at a height of 15 ft above ground.
** Wind speeds were measured at a height of 6 ft above ground.
† Insufficient or no valid data for determining monthly average.

Table 8

Maximum Solar Radiation for Red Devil and Turkey Creek

| | Maximum Solar Radiation, Ly/min | | | | | |
|---|---|---|---|---|---|---|
| Month | Total Hours of Valid Data | Average | Range | Total Hours of Valid Data | Average | Range |
| | Red Devil Station | | | Turkey Creek Station | | |
| Feb 76 | 670 | 1.07 | 0.48-1.22 | 103 | 0.94 | 0.91-0.98 |
| Mar 76 | 717 | 1.31 | 0.41-1.50 | 659 | 1.37 | 0.31-1.52 |
| Apr 76 | 663 | 1.40 | 0.50-1.57 | 718 | 1.52 | 0.66-1.61 |
| | Red Devil Sediment Basin | | | Turkey Creek Sediment Basin | | |
| May 76 | 448 | 1.40 | 0.54-1.57 | 456 | 1.50 | 0.63-1.62 |
| Jun 76 | 664 | 1.52 | 0.32-1.63 | * | * | * |
| Jul 76 | 605 | 1.58 | 0.77-1.73 | * | * | * |
| Aug 76 | 640 | 1.47 | 0.41-1.65 | * | * | * |
| Sep 76 | 682 | 1.46 | 0.68-1.71 | 682 | 1.38 | 0.44-1.49 |
| Oct 76 | 324 | 1.38 | 0.96-1.46 | 145 | 1.12 | 0.77-1.31 |
| Nov 76 | 279 | 1.06 | 0.39-1.23 | 276 | 0.76 | 0.55-1.13 |
| Dec 76 | 676 | 1.09 | 0.76-1.24 | 355 | 0.77 | 0.55-0.82 |
| Jan 77 | 464 | 1.15 | 0.64-1.28 | * | * | * |

* Insufficient valid data for determining monthly average.

Table 9

Air Temperatures for Red Devil and Turkey Creek

| | Air Temperature, °F | | | | | |
|---|---|---|---|---|---|---|
| Month | Total Hours of Valid Data | Average | Range | Total Hours of Valid Data | Average | Range |
| | Red Devil Station | | | Turkey Creek Station | | |
| Nov 75 | 248 | 50 | 2-62 | 250 | 29 | 2-65 |
| Dec 75 | 712 | 54 | 4-75 | 390 | 36 | 3-70 |
| Jan 76 | 736 | 55 | 1-72 | 153 | 40 | 10-66 |
| Feb 76 | 670 | 60 | 8-74 | 98 | 43 | 2-69 |
| Mar 76 | 717 | 55 | 2-72 | 659 | 37 | -8-73 |
| Apr 76 | 660 | 65 | 24-8 | 718 | 45 | 19-79 |
| | Red Devil Sediment Basin | | | Turkey Creek Sediment Basin | | |
| May 76 | 436 | 70 | 35-83 | 474 | * | * |
| Jun 76 | 696 | 80 | 40-98 | 696 | * | * |
| Jul 76 | 744 | 85 | 52-102 | 744 | * | * |
| Aug 76 | 739 | 82 | 50-92 | 730 | * | * |
| Sep 76 | 720 | 75 | 38-95 | 686 | 75 | 41-90 |
| Oct 76 | 325 | 73 | 32-81 | 145 | 70 | 20-79 |
| Nov 76 | 275 | 50 | 20-72 | 266 | 40 | -10-70 |
| Dec 76 | 671 | 48 | 20-64 | 356 | 38 | 5-55 |
| Jan 77 | 447 | 50 | 20-68 | * | * | * |
| Feb 77 | 255 | 53 | 20-65 | 271 | 50 | 20-66 |
| Mar 77 | * | * | * | 742 | 60 | 20-67 |

* Insufficient valid data for determining monthly average.

# APPENDIX A: SENSORS USED WITH MANUALLY OPERATED AND AUTOMATED FIELD STATIONS AT FORT CARSON, COLORADO

1. All sensors used by the WES at Fort Carson for environmental data collection, together with appropriate mathematical conversions of the raw field data into engineering units, are described in the following paragraphs.

## Rainfall

2. Rainfall was measured continuously with a Weather Measure* Model P-501 rain gage. All internal parts are aluminum, chrome-plated brass, or stainless steel. The rain gage has an 8-in.-diam orifice protected by a heavy brass ring and uses a tipping-bucket mechanism coupled to a mercury switch to produce an electric output signal. The tipping-bucket mechanism (Figure A1) uses balanced polyethylene buckets suspended on stainless steel pivots.

3. As rainfall enters the orifice, it is drained to the gage's interior into one of the two buckets in the tipping mechanism. When one bucket is full, the weight of the water causes it to tip and the second bucket swings into place beneath the entry funnel. As each bucket tips, the water drains out through the base of the gage where it can be accumulated and analyzed, if desired. The tipping action causes a mercury switch beneath the tipping-bucket mechanism to close momentarily. The gage is calibrated such that one switch closure is produced for each 0.01 in. of rainfall. The number of switch closures during an interrogation interval is counted, and the total is transferred to the cassette tape. Later, appropriate software is used to calculate the total rainfall (in inches) for the interrogation interval. The conversion is

$$\text{Rainfall} = \text{number of switch closures (counts) for the specified recording period} \times 0.01$$

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* Weather Measure Corporation, Sacramento, California.

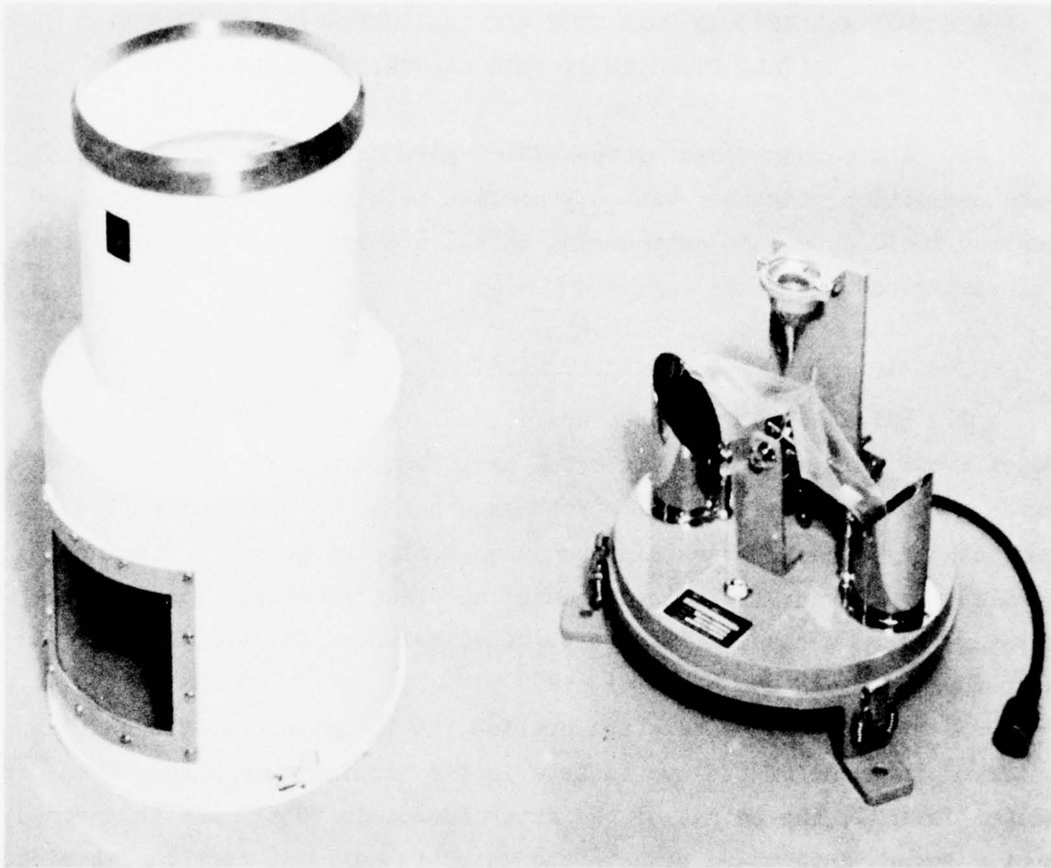

Figure A1. Interior of Weather Measure Model P-501 rain gage showing tipping-bucket mechanism

## Solar Radiation

4. Solar radiation was measured with two Matrix* Mark I-G Sol-A-Meters (Figure A2). This sensor is composed of a silicon photovoltaic cell pyranometer with a spectral response from 0.35 to 1.15 μm with a peak sensitivity of 0.85 μm. It is temperature compensated (-72° to +140°F) and generates a millivolt signal output that is proportional to the total incident radiation. The cell is mounted under a rugged Pyrex hemisphere for protection and takes less than 1 msec for 0-100 percent response.

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* Matrix Inc., Mesa, Arizona.

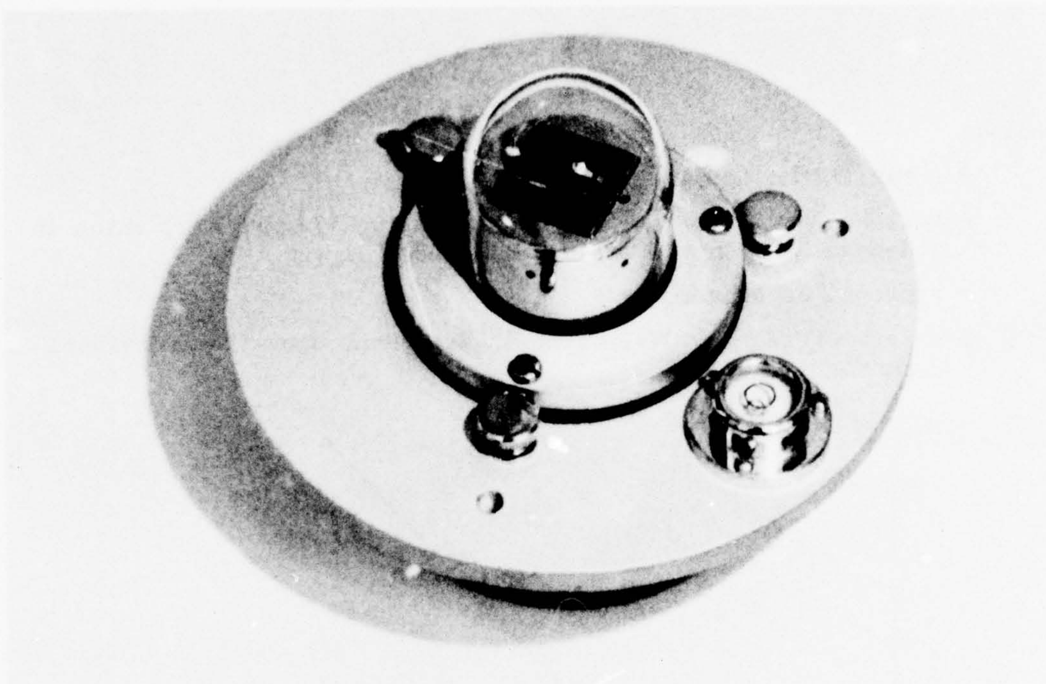

Figure A2. Matrix Mark I-G Sol-A-Meter

5. Some other characteristics of the Matrix Sol-A-Meter are as follows:

a. Range (nominal): 0-2 Ly/min.

b. Calibrated accuracy: ±5 percent.

c. Size: base diameter, 5 in.

d. Weight: 1-1/2 lb.

6. The Sol-A-Meter can be used to measure (a) incident radiation over its entire bandwidth (i.e. 0.35-1.15 μm), (b) reflected radiation by inverting the sensor, and (c) radiation in a specific bandwidth by using special filters. Only incident radiation was measured at Fort Carson, Colorado.

7. Each Sol-A-Meter was precalibrated at the factory by comparison with a thermopile-type radiometer in bright sunshine on clear days. An example factory calibration curve is given in Figure A3.

8. The signal output of the sensor is related to solar radiation by the following equation:

$$R = av + b$$

where

R = radiation, Ly/min

a = slope ($\approx 0.02$) of the calibration curve (Figure A3), which is dependent upon the individual sensor

v = output of sensor, mv

b = zero offset ($\approx 0.04$), which is dependent upon the individual sensor

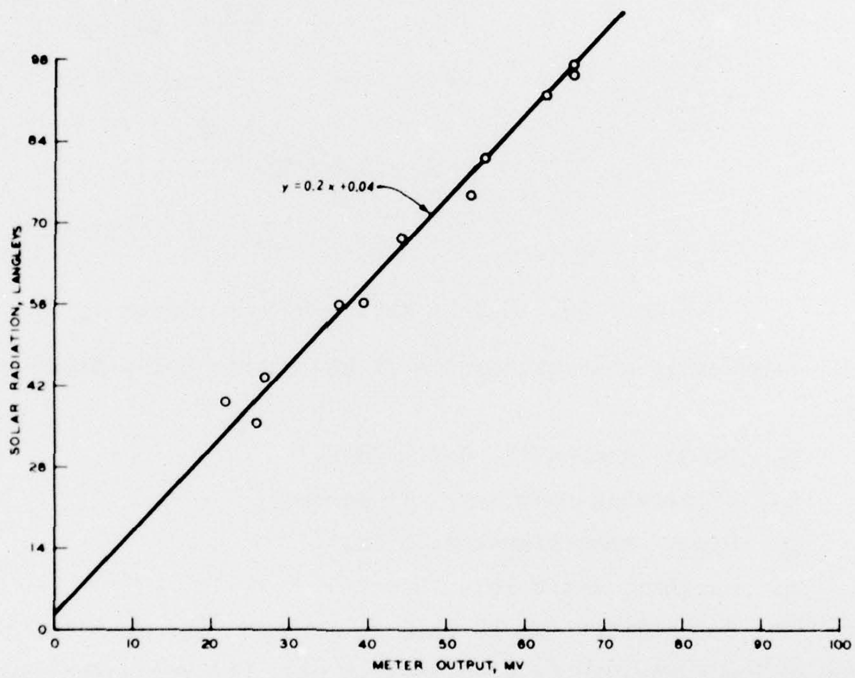


Figure A.3 Example calibration curve for Matrix Mark I-G Sol-A-Meter

## Air Temperature

9. Air temperature was measured with a Lockheed (LEC) Model S1081 sensor (Figure A4). This sensor incorporates a thermolinear thermistor network as the sensing element. The network is a composite device consisting of resistors and thermistors configured to produce an output resistance that is related to temperature as follows:

$$t = \left[ \left( \frac{R_t - k_2}{k_1} \right) \times 1.8 \right] + 32.0$$

where

$t$ = temperature, °F

$R_t$ = total sensor resistance, ohms

$k_2$ = 12,176 ohms/°F

$k_1$ = 127 ohms/°F

10. The sensor enclosure is constructed with a triple shield that eliminates the effect of both direct and reflected solar radiation upon the sensing element. A "chimney" design creates a smooth flow of the ambient air around the sensing element without forced aspiration. The temperature sensor produces a linear output of 0-1.0v over a temperature sensor range of -72° to +140°F. Characteristics of Model S1081 temperature sensor are given below.

a. Temperature range: -72° to +140°F.

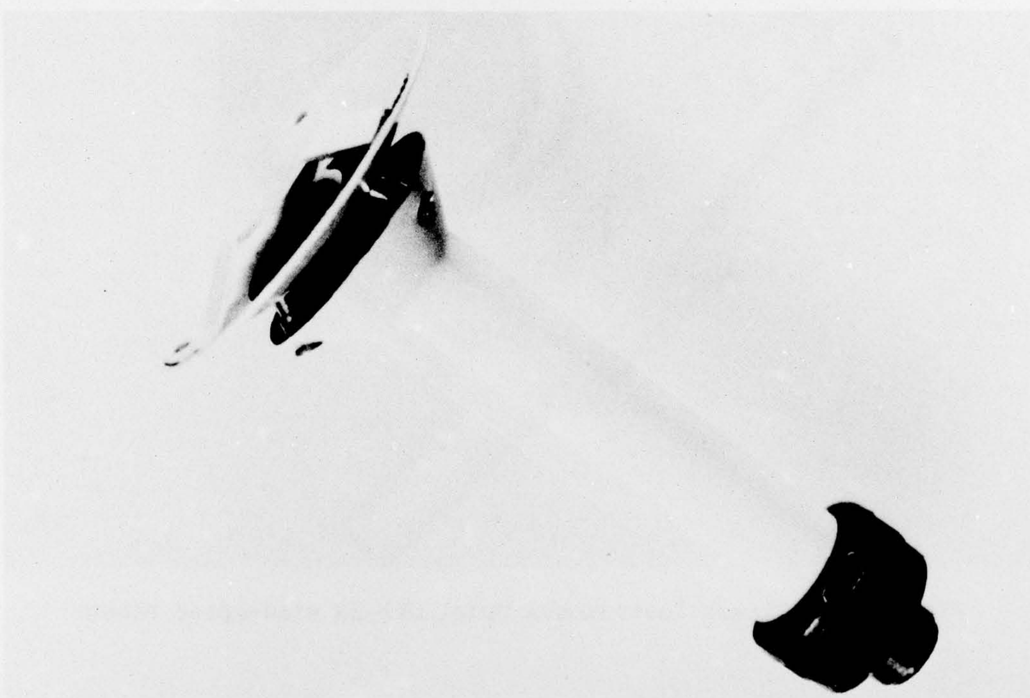

Figure A4. The LEC Model S1081 air-temperature sensor

b. Calibrated accuracy: $\pm 0.27°F$.

c. Sensitivity: 127 ohms/°F.

11. Air temperature (in °F) is determined by the following equation:

$$\text{Air temperature} = \left[\left(\frac{\text{Recorded value} - 400}{10}\right) \times 1.8\right] + 32.0$$

where

400 = zero offset constant

## Wind Speed

12. Wind speed was measured at 6.5 ft above ground level continuously with a Climet* Model 011-2B wind-speed sensor (Figure A5), an

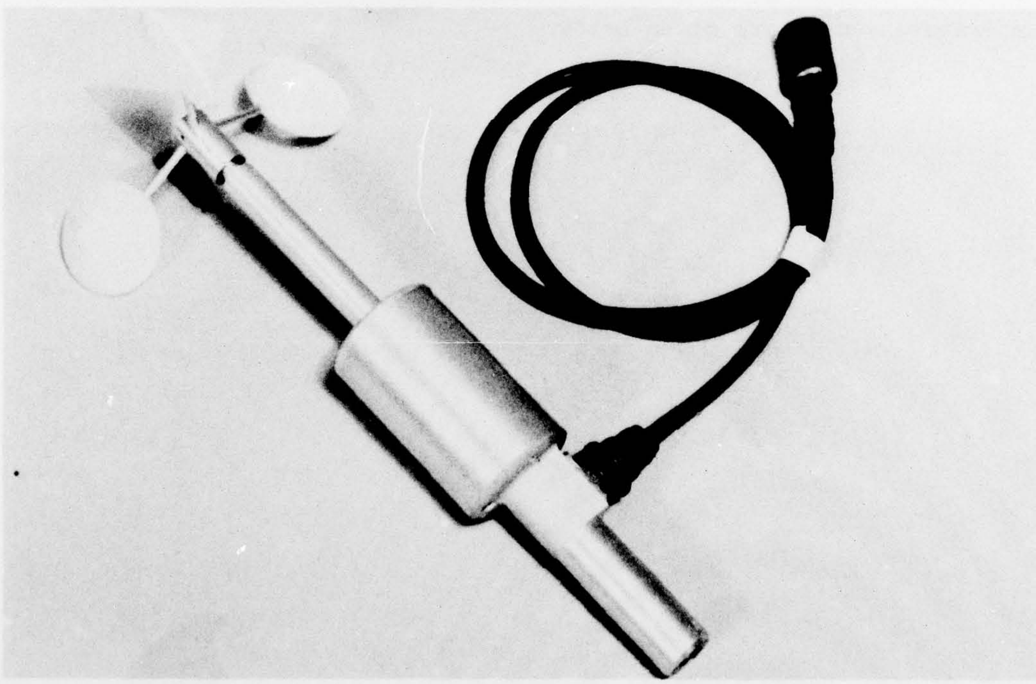

Figure A5. Climet Instruments Model 011-2B wind-speed sensor

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* Climet Instruments, Sunnyvale, California.

accurate, durable, 3-cup-type, 0- to 100-mph anemometer. As the anemometer rotates, it activates a sealed magnetic reed switch by means of a magnet attached to the sensor shaft. The output signal is a series of contact closures at a frequency proportional to wind speed. Reliability of the sensor is ensured by incorporation of rugged materials; namely, Lexan anemometer cups, a stainless steel shaft, Teflon-sealed stainless steel bearings, cast and machined anodized aluminum housing, etc., and careful selection of seals and weatherproof connectors.

13. Detailed characteristics of the wind-speed sensor are as follows:

- a. Range: 0-100 mph.
- b. Calibrated accuracy: $\pm 2$ percent or 0.25 mph, whichever is greater.
- c. Output: 2 switch closures per revolution.

14. The switch closures during each preselected sampling time interval are counted, and the total number is transferred to magnetic tape. An average speed over the time interval (in mph) is then obtained by applying the appropriate constant in the equation:

$$\text{Average wind speed} = \text{number of switch closures} \times (X_i)$$

where

$X_i$ = the constant for time interval $i$

$i$ = time interval in minutes; for $i = 15$ min, $X = 0.001753$ ; for $i = 30$ min, $X = 0.000876$ ; for $i = 60$ min, $X = 0.000438$

## Wind Direction

15. Wind direction was measured at 6.5 ft above ground level by a Climet Model 012-2B wind-direction sensor (Figure A6), which is a companion to the 011-2B wind-speed sensor (Figure A5). An airfoil wind vane and precision potentiometer assembly deliver a resistance analogous to the azimuth bearing from which the wind is blowing. The wind-direction sensor is made of the same rugged materials and has the same type of seals as the wind-speed sensor.

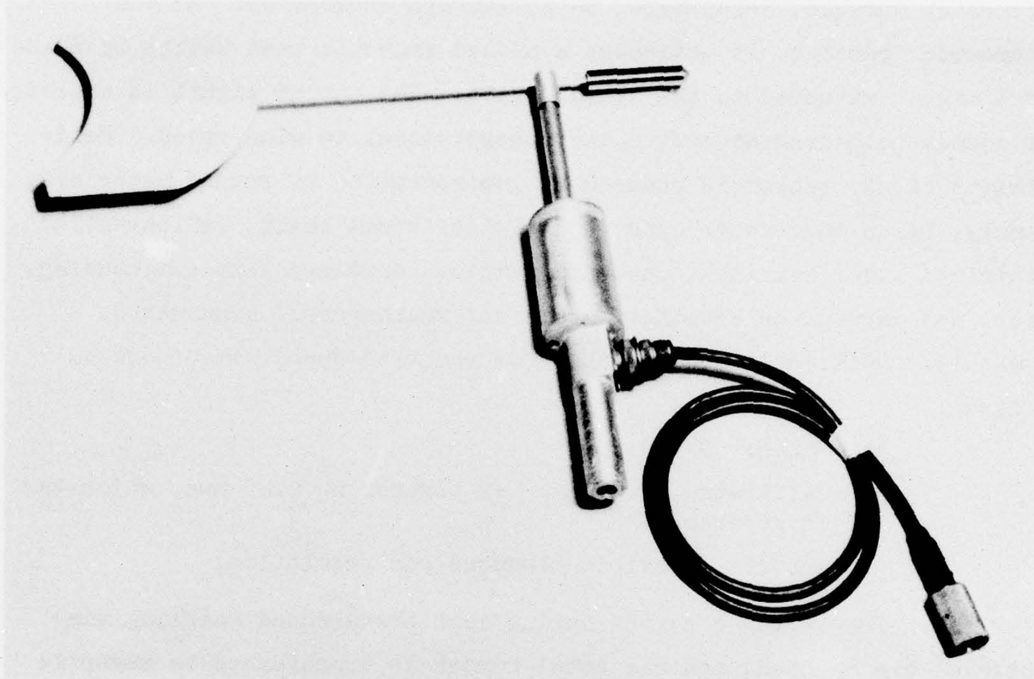

Figure A6. Climet Instruments Model 012-2B wind-direction sensor

16. Detailed characteristics of the wind-direction sensor are listed below.

a. Mechanical azimuth range: 0-360 deg.

b. Electrical azimuth range: 0-354 $\pm$ 2 deg.

c. Calibrated accuracy: $\pm$5 deg.

d. Resolution: 0.5 deg.

e. Minimum wind speed for direction measurement: 1.25 mph

17. A sensor output of 15,000 ohms corresponds to an azimuth of 0 deg (tape value = 0), and 5,000 ohms corresponds to an azimuth of 356 deg (tape value = 712). A "dead band," 357-359 deg, exists for which the sensor has no output, and all azimuths in this range are interpreted as 358 deg. The conversion of the recorded tape value to wind direction in degrees from north (clockwise) is expressed as:

$$\text{Wind direction} = \frac{\text{recorded tape value}}{2}$$

## Water Level

18. Water level was measured with a Universal Engineered Systems* Model T-66 position water-level sensor (Figure A7) and still well.

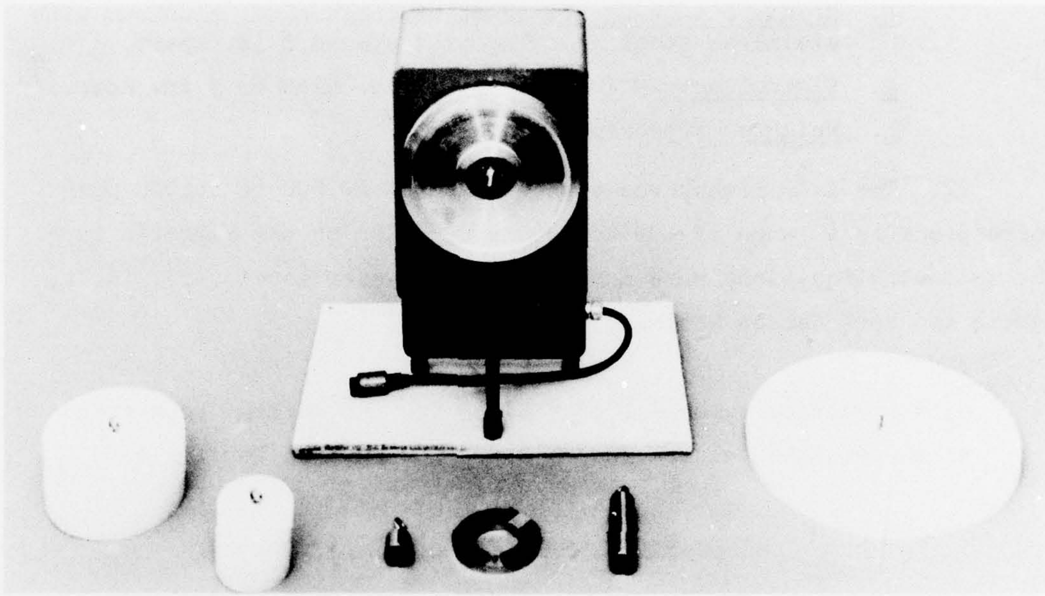

Figure A7. Universal Engineered Systems Model T-66 water-level sensor

19. As installed in the field, the water-level sensor (Model T-66) is mounted on a horizontal platform above the water surface to be measured. A polymer float rides on the water surface and is connected by a stainless steel tape to the tape wheel and gearbox, which, in turn, position a precision potentiometer as the water rises and falls. Optimum sensitivity is provided by antibacklash gears and precision stainless steel bearings. The T-66 is contained in an all-weather cast aluminum enclosure and has a tripod mounting for level adjustment. The function of the still well is to provide a plane surface free of ripples upon which the float can ride.

20. Characteristics of the T-66 water-level sensor are as follows:

a. Range of measurements: 0-10 ft.

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* Universal Engineered Systems, Pleasanton, California.

b. Calibrated accuracy: 0.2 percent.

c. Sensitivity: 0.05 percent.

d. Resistance: potentiometer, 10,000 to 15,000 ohms.

e. Floats: extruded polymer, 12 in.

f. Standard tape wheel: 2-ft circumference; aluminum with stainless steel indexing pins spaced 6 in. apart.

g. Dimensions: 9 in. wide by 18 in. high by 9 in. deep.

h. Weight: approximately 20 lb.

21. The T-66 linear resistance range of 10,000 to 15,000 ohms corresponds to a range of 100 to 900 mv recorded on the magnetic tape. The following equations were used to compute water level ($W_L$), in ft, in the two Fort Carson sediment basins:

$$W_L = (\text{recorded value} - 100) \times 0.033 \text{ for the Turkey Creek site}$$
$$W_L = (\text{recorded value} - 100) \times 0.025 \text{ for the Red Devil site}$$

## Water-Quality Sensors

22. Two different sensor packages were used by the WES on Clover Ditch to determine selected characteristics of the surface waters. At site 10 on Clover Ditch at which the WES automated field station was established on 20 November 1975, a Martek* Mark V water-quality sensor package (Figure A8) containing sensors for measuring pH, conductivity, temperature, and D.O. was used. For the manual station that was established at site 6 on Clover Ditch on 20 November 1975, a Martek Mark II sensor package (Figures A9 and A10) containing the same four types of sensors was used until the WES installed an automated field station at site 6 on 5 May 1976. At the time the automated field station was established, a Martex Mark V sensor package was installed at site 6, and the Martex Mark II sensor package was moved to another location at Fort Carson.

23. The Martex Mark II and V sensor packages (pH, conductivity,

* Martek Inc., Newport Beach, California.

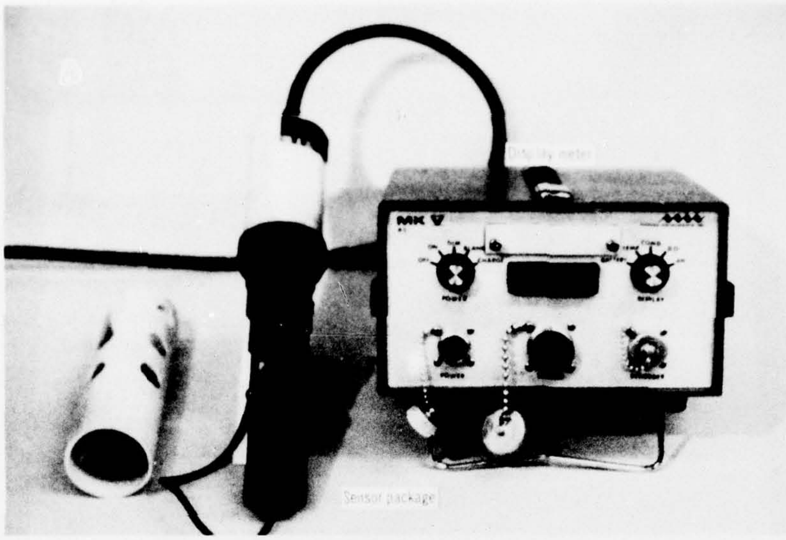


Figure A8. Martek Instruments Mark V water-quality sensor package

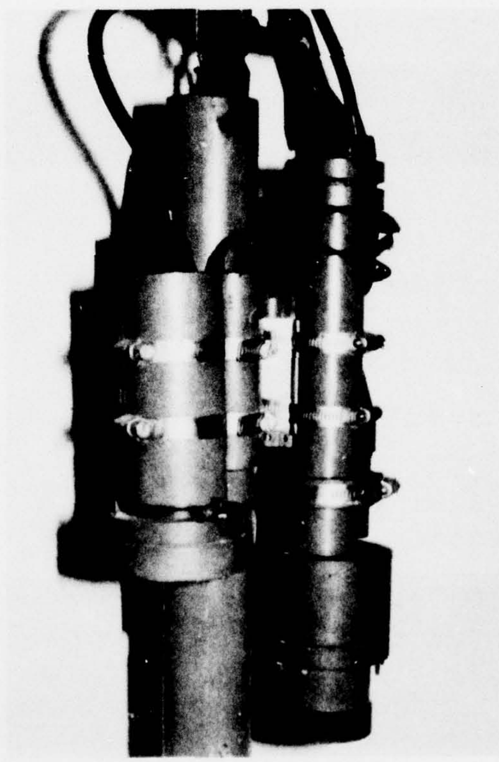

Figure A9. Martek Instruments Mark II water-quality sensor package

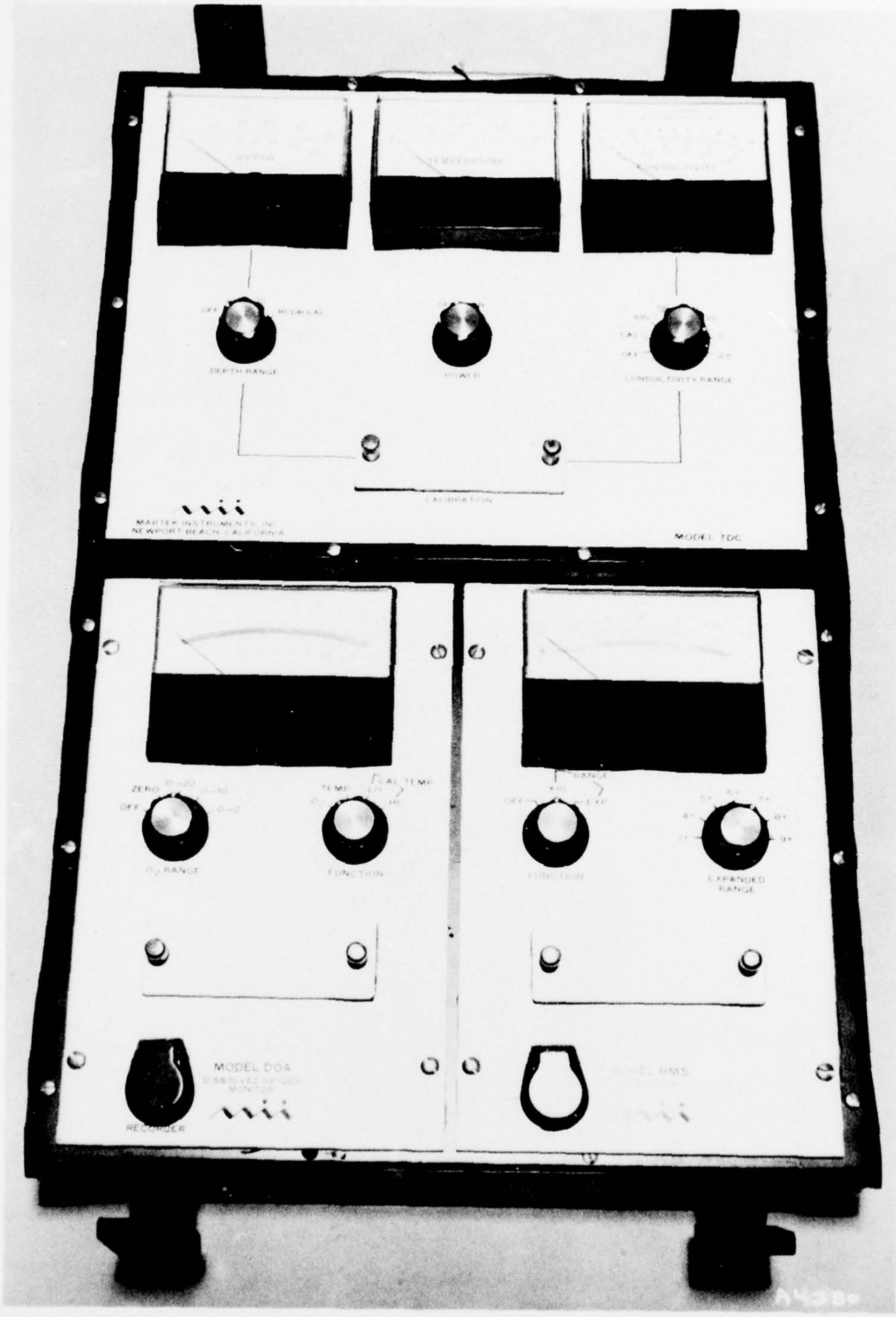


Figure A10. Display meter of Mark II water-quality sensor package

D.O., and temperature) also require 12-v DC of external power for operation. Power supply is provided by the use of a lead-calcium wet-cell battery interfaced with a solar panel and voltage regulator (Figure A11).

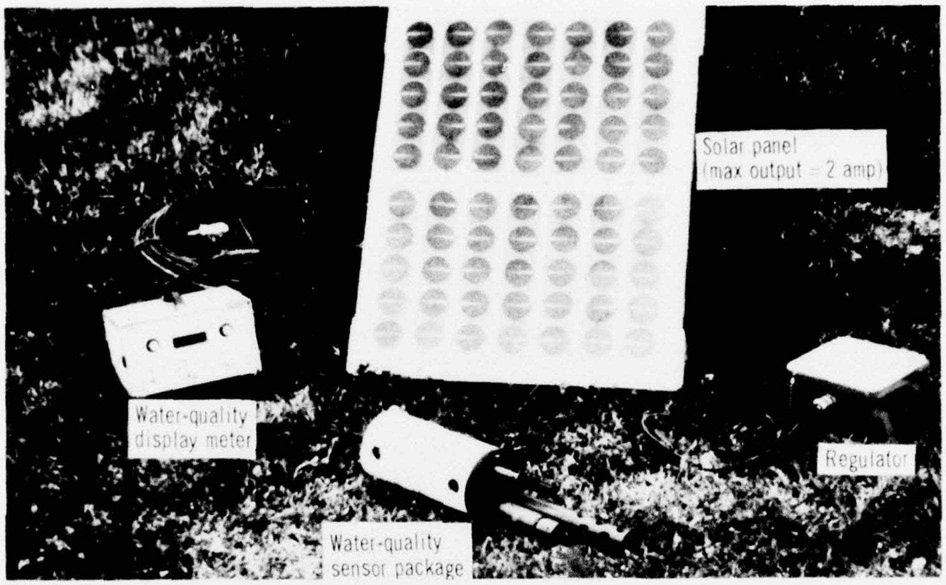


Figure A11. Solar panel interfaced with Mark V water-quality sensor package

24. The descriptions of the individual sensors as contained in the Martek Mark II and Mark V sensor packages are given in the following paragraphs.

Concentration of
hydrogen ions (pH)

25. The negative logarithm of the hydrogen ion concentration is expressed as pH in gram-ions per litre. The pH scale varies from 0 to 14 and is based on the ionization of pure water. It is measured by sensing the potential difference between a reference electrode and a glass pH electrode. The magnitude of this potential difference, or signal, is 59.2 mv per unit of pH at 77°F; at pH 7 (neither acidic nor basic), the signal is from 0 to ±50 mv, the actual value depending on the individual characteristics of the particular glass electrode used. For accuracy, all pH measuring systems must be temperature compensated;

this is accomplished by a temperature-sensitive resistor or thermistor included in the pH amplifier circuit.

26. The two Martek Instruments used by the WES are characterized below.

| | Mark II | Mark V |
|---|---|---|
| Range, pH | 0-12 | 0-12 |
| Calibrated accuracy, pH | $\pm$0.1 | $\pm$0.03 |
| Resolution, pH | 0.01 | 0.01 |
| Operating temperature range, °F | 0-122 | 0-122 |
| Output, mv | 0-500 | 0-1000 |

27. Signal conditioning for the Mark V pH sensor was set up so that the output range is from 0 to 1000 mv recorded on the cassette tape. The tape value is converted to pH by the following computation:

$$\text{pH} = \text{recorded value} \times 0.014$$

<u>Dissolved oxygen</u>

28. Martek polarographic D.O. sensors are used; each consists of a silver anode and a gold cathode enclosed in a PVC (polyvinylchloride) housing. A solution of potassium chloride is used as the electrolyte. A membrane, permeable to oxygen, is placed over the cathode. The membrane material is a special, tough Teflon, which has the characteristic ultrasmooth surface that helps prevent foreign materials, such as sludge, slime, grease, and marine organisms, from clinging to it. Aside from diffusing oxygen and other gases, it effectively shields the cathode and anode from contamination, prolonging their service life. When oxygen diffuses through the membrane to the cathode, a chemical reaction takes place:

$$O_2 + 2H_2O + 4e \longrightarrow 4OH$$

The related reaction at the silver anode in the electrolyte chamber is

$$4Ag + 4Cl \longrightarrow 4AgCl + 4e$$

A voltage applied across the two electrodes results in a current flow that is proportional to the partial pressure of oxygen at the probe tip, and the sensor produces an output signal as long as the electrolyte is exposed to oxygen. A pressure-equalizing diaphragm, on the side of the probe housing, flexes as necessary to provide pressure equalization across the Teflon membrane (in between the water sample and the electrolyte chamber), which is necessary when a closed electrolyte chamber is operated to and from water depths up to 328 ft.

29. The two sensor packages (Martek Mark II and V) are primarily intended for use in natural water bodies. The Mark II provides fast response to changes in D.O. level because of the use of a special stirrer mechanism and a very thin, rapidly responding membrane. A similar fast response is obtained with the Mark V by use of a special scraper, which is actually more effective in preventing contamination of the probe than is the stirrer.

30. A separate underwater temperature probe supplied with the Martek units is used to measure water temperature for the primary purpose of calibrating oxygen partial pressure values (as sensed by the D.O. probe) in terms of ppm. The temperature probe uses a factory-calibrated and aged disc-type thermistor with a time constant of approximately 10 sec as the sensing element. It forms part of an automatic temperature-compensation circuit, which corrects D.O. readings for both temperature effects on the oxygen probe membrane permeability and variation in oxygen solubility in natural waters as a function of temperature.

31. The two Martek D.O. sensors are compared below.

| | Mark II | Mark V |
|---|---|---|
| Range, ppm | 0-2, 0-10, 0-20 | 0-20 |
| Calibrated accuracy, ppm | ±1.0% of full scale | ±0.05 |
| Resolution, ppm | 0.05 | 0.01 |
| Operating range, °F | 0 to +104 | -22 to 158 |
| Output, mv | 0-500 | 0-1000 |

32. Signal conditioning for the Mark V D.O. sensor was set up so that it produces a 0- to 1000-mv output for 0- to full-scale input from

the D.O. sensor. The recorded tape value is converted to D.O. in ppm by the equation:

$$\text{D.O.} = \text{recorded value} \times 0.02$$

Water conductivity

33. Electrolytic conductivity of solutions is a nonspecific measurement of the ions in a solution. The values obtained are a function of the number of ions, their electrical charge, and their rate of movement, which is also a function of temperature and the nature of the ion. Moreover, the magnitude of the temperature effects is different for the different ions and changes with concentration. Finally, it should be pointed out that the conductivity is not a linear function of the number of ions in the solution. For example, the use of electrical conductivity to obtain the exact concentration of salts in solution is restricted to solutions of known compositions such as seawater. When seawater is diluted by fresh water such as in an estuary, errors caused by changes in salt composition and dilution will result in less than accurate results. The use of conductivity data in very dilute solutions, as in fresh water to obtain concentration of dissolved salts, is an estimate at best. This measurement is based on a variation of Ohm's law:

$$\text{Conductance in } \mu\text{mhos} = \frac{\text{current}}{\text{voltage}}$$

Thus, if the voltage drop across two electrodes is kept constant, conductance is directly proportional to the current through the cell. This is the principle employed in the Mark II and Mark V packages.

34. The conductivity-measuring circuit in the Mark II and Mark V units consists of a very closely regulated 1000-Hz sine wave generator, which feeds its output (0.5v) to the conductivity cell. The current passing through the cell is fed to a current-to-voltage converter, where it is changed to an a-c voltage proportional to conductance. This a-c voltage is then converted to a pulsating d-c voltage by a phase detector,

and the resulting voltage can be read on a display meter supplied with the Mark II and Mark V and, by suitable signal conditioning, simultaneously output to the field station. Since the phase detector is sensitive only to that part of the signal that is in phase with the applied voltage, the overall circuit sees only the cell resistance, not the cable capacitance, which would cause large errors. The conductivity cell has large nickel electrodes, which are coated with platinum black to increase the surface area, reducing resistive effects at the electrode surfaces.

35. Characteristics of the two Martek conductivity sensors are listed below.

| | Mark II | Mark V |
|---|---|---|
| Range, μmhos/cm | 0-100, 50, 25, 10, 5, 2.5 | 0-1000 or 0-100 |
| Calibrated accuracy | 2% of full scale | ±5.0 or ±0.5 μmhos/cm |
| Resolution | 0.1% of full scale | 1.0 or 0.1 μmhos/cm |

36. Signal conditioning for the Mark V conductivity sensor was set to produce a recorded output of 0 to 1.0v, analogous to 0- to full-scale sensor output. Therefore, the recorded value equals conductivity in μmhos/cm, and no conversion is required.

Water temperature

37. Water-temperature sensors are included in both of the Martek sensor packages, but two different tranducers are used. The Mark II uses a thermistor, and the Mark V uses a thermolinear array.

38. The following are the characteristics of the two Martek temperature sensors:

| | Mark II | Mark V |
|---|---|---|
| Range, °F | 0 to +104 | +23 to +113 |
| Calibrated accuracy, °F | ±0.5 | ±0.1 |
| Resolution, °F | 0.01 | 0.01 |

39. Signal conditioning for the Mark V water-temperature sensor was set up to produce a range of 0 to 1.0v recorded on the magnetic tape for 0- to full-scale output of the sensor. The conversion to water temperature in °F is obtained as follows:

$$\text{Water temperature} = [(\text{recorded value} \times 0.045) \times 1.8] + 32.0$$

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.


West, Harold W

Environmental baseline descriptions for use in the management of Fort Carson natural resources; Report 2: Water-quality, meteorologic, and hydrologic data collected with automated field stations / by Harold W. West, Herman M. Floyd. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.

43, [10], 17 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-77-4, Report 2)

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